Allocation coefficients of nitrogen fertilizers for polycultures of coffee production

Report to SAI Platform
for the attention of Brian Lindsay
Project Leader – GHG Emissions –
LCA Dairy, Beef and Coffee

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1 Introduction

Using the ISO 14044 hierarchy guidance for allocation, the Technical Working Group (TWG) of the Green Coffee PCR project agreed to establish a list of ratios based on the nitrogen uptake (based on 'fresh weight productivity of both coffee and 'intercrop') of a range of different intercropped systems. In this context, this document briefly describes the approach that has been applied and the data sources that have been used for calculation of proper allocation ratios. An additional Excel table is attached as annex, setting out the detailed information on which the calculation is based.

2 Aim of the study

The aim of the study is to establish a list of default values relating to allocation ratios for typical crops grown in polyculture with coffee, based on the plants' nitrogen uptake. These default values serve as the basis for calculating the allocation of the nitrogen fertilisers between coffee and other crops in different intercropping systems, if the quantities of fertiliser to be applied to individual intercrops cannot be specified by farmers.

It should be stressed that the established default value table can only reflect the general circumstances of coffee intercropping systems. There is, however, some uncertainty associated to this data. The nitrogen uptake by coffee and other intercrops may vary depending, e.g. soil and climate conditions, lighting conditions, balance of nutrients, interaction between crops and nutrients. Fageria (2009) indicated that plants have a remarkable ability to regulate nutrient uptake according to their growth demand. However, it is not possible to draft a universal scenario or to cover all specific situations. The highest priority in dealing with the allocation issue should be afforded to the use of primary data. In this respect, farmers should be aware of the quantities of fertilizers used for intercrops. Optimisation of the use of fertilizers can help to reduce the environmental impact and to save money. If it is not possible to collect data on the quantities used by the farmers, the farmers should be encouraged to make estimation. They know how many coffee trees they have and should also know roughly how much fertiliser they use for each tree, as these fertilisers are applied manually in a ring around the tree stem. If the approximate amount is still not feasible, these default values can serve as a basis for allocation.

As required by the briefing paper of SAI platform, the analysis focuses on the ten most important coffee intercropping systems and will set out ratios based on the plants' nitrogen uptake for the following plants:

- Avocado
- Banana
- Beans
- Citrus
- Durian
- Maize
- Mango
- Papaya
- Pepper
- Plantain

Systems with three or more crops or with other types of agricultural plants are not in the scope of this study.

3 Short Description of methodological approach

A brief literature review is conducted firstly taking into account published research about the nitrogen nutrient uptake of both coffee and 10 other crops. Some studies investigated the agronomic performance or fertilizer use of intercropping systems, e.g. Opoku-Ameyam et al. (2003); FAO (1982). However, data on nitrogen requirements in investigated intercropping systems could not be found within the stipulated time period. Therefore, we shifted our focus towards the individual crops in monoculture systems, since the nitrogen uptake of individual crops in mono- and polyculture should be the same from a plant nutrition point of view.

To find out the appropriate allocation, the approach is based on the nitrogen nutrient uptake on a crop-by-crop basis. Nutrient uptake includes nutrients lost in crop, pruning, and nutrients used for the growth, development and maintenance of the tree (Harding 1992). This approach focuses on the plant itself. Compared to the fertilizer application – where usually more fertilizers are applied on the field than required by the plants – this approach does not take the fertilizer losses (e.g. soil leaching) into consideration. The losses vary largely depending on, e.g., soil and climate conditions. Therefore, the advantage of this approach is that external factors such as country-specific soil or climate conditions can be neglected, as the nitrogen nutrient taken up by the same crop remains relatively constant. It is therefore assumed that the fertilizer losses are similar for two crop types planted in intercropping system, since these intercrops are grown on the same ground and under the same conditions.

Another approach based on the fertilizer rate is applied if the data on nitrogen uptake is difficult to obtain[1]. The fertilizer application rate of crops can be found in the FAO database. However, the amounts of fertilizer applied depend on various agro-ecological factors, e.g. soil, climate and terrain. The fertilizer application rate also takes account of the losses incurred. Thus, the Nutrient Uptake Efficiency (NUE) can be applied to calculate the uptake of nitrogen based on the amount of fertilizer used.

[1] Unlike data on fertilizer application, there are few data sources on nitrogen uptake. Some studies, for example, analyse the nutrient uptake in fruits, in other words, the nutrient removal after harvesting. Other studies, however, investigate the nutrient uptake in leaves. What we are looking for is the nitrogen uptake by a whole tree including leaves, stem, braches, root, flower, fruit etc. Furthermore, although some studies indicate the nutrient uptake of a whole tree, the yield is unknown. This makes it difficult to convert the data into the nutrient uptake based on fresh weight productivity.

4 Results based on a literature review

4.1 Coffee

The global production of coffee in 2010 was 8.2 million tonnes (FAO 2013). This corresponds to 137 million 60-kg bags. Depending on different statistical sources (Marsh 2007; Harding 1992; ITC 2013), Arabica coffee accounts for about 60%-80%, while Robusta coffee represents app. 20%–40% of world production, respectively.

Robusta coffee generally requires fewer nutrients than Arabica (Harding 1992). Table 2 shows the specific amount of nitrogen uptake differentiated according to Arabica and Robusta coffee from Harding (1992). Robusta coffee generally generates a higher yield than Arabica. Waireg & Van Asten (2012) indicated that the yield of Arabica ranged from 0.1 to 1.8 kg per tree and of Robusta from 0.5 to 3.6 kg per tree. The nitrogen uptake of Arabica per kg green bean is therefore higher than that of Robusta per kg green bean.

The following table provides an overview of the nutrient uptake of Arabica and Robusta coffee as analysed by Harding (1992).

Table 1: Nutrient uptake (taken from Harding 1992)

Nutrient uptake - Macronutrients								
Coffee type	Country	Source	kg/ha/year					
			N	P2O5	K2O	MgO	CaO	S
Arabica (1)	Brazil	Malavolta, 1990	167.4	17.9	164.0	54.1	90.6	13.7
Arabica (2)	Costa Rica	Carvajal et al., 1969	172	36	119	20	53	-
Arabica (3)	Kenya	Cannell and Kimeu, 1971	150	23	180	25	77	-
Robusta (4)	Cote d'Ivoire	Snoeck, 1983	85.2	17.6	82.1	20.5	54.8	-
Robusta (5)	Indonesia	Saleh, 1983	53.2	10.5	80.7	16.5	28.0	-

Notes:
(1) Mundo Novo and Catuai varieties, 5.5-6.5 years old, 1250 covas/ha, 2 stems/cova, yield 3 000 kg/ha green bean.
(2) Bourbon variety, 3-4 years old growing in nutrient solution, equivalent uptake by 1 500 trees.
(3) Five year old trees, 1 500 trees/ha, yield 1 100 kg/ha gb.
(4) Five year old trees, 1 333 trees/ha, yield 1 000 kg/ha gb.
(5) 1 200 - 1 600 trees/ha, shaded, yield 1 500 - 2 000 kg/ha gb.

The nitrogen uptake per kg of green bean can be calculated on the basis of the nitrogen values and the corresponding yield indicated in the table above (see Table 2).

Table 2: Nitrogen nutrient uptake by Coffee according to Harding 1992

Coffee type	Country	N (kg/ha/year)	Yield (kg/ha)	kg /kg Green coffee	kg/kg Cherry	Average values (kg / kg Cherry)
Arabica	Brazil	167,4	3000	0,06	0,011	**0,022**
	Costa Rica	172	1200 *	0,14	0,029	
	Kenya	150	1100	0,14	0,027	
Robusta	Cote d'Ivoire	85,2	1000	0,09	0,017	**0,012**
	Indonesia	53,2	1750 (average)	0,03	0,006	

** based on (FAO 2013)*

The results show that the range of nitrogen uptake per kg of green bean is very broad even within the same coffee type. For Arabica, nitrogen uptake accounts for 0.06 to 0.14 kg per kg of green bean, while a range of 0.03 to 0.09 kg was identified for Robusta. As indicated in the beginning, these differences are neglected as the specific situations cannot be considered. The standard deviation is specified, along with the average, to allow for confirming the relevance of result variance by means of sensitivity analysis.

The data on yield extracted from literature refer to green coffee. Therefore, the data referring to green coffee were converted to fresh cherries. Generally, abound 6 kg or 5 kg of fresh cherries produce 1 kg of green coffee beans (Winston et al. 2005a; Nestlé 2007). The factor of 5 is used for the conversion based on a conservative approach.

Further data on nitrogen uptake can be found in Van der Vossen (2005) and Winston et al. (2005b) (see Table 3). The results of Arabic coffee are generally comparable to the range of results from Harding (1992).

Table 3: Nitrogen uptake by Arabica Coffee according to Van der Vossen 2005

Nitrogen uptake (kg N/ha)	Yield (t Green coffee/ha)	Nitrogen uptake (kg N/kg green bean)	Nitrogen uptake (kg/kg Cherry)
135	1	0.135	0.027
112	1	0.112	0.022

A summary of the results including averages and standard deviations is presented in the table below. The factor determining the difference of nitrogen uptake by Arabica and Robusta coffee is 2.

Table 4: Average nitrogen uptake by Arabica and Robusta coffee

	Source	Nitrogen uptake (kg/kg Cherry)	Average (kg N/kg Cherry)	Standard deviation
Arabica	Harding 1992	0.011	0.023	0.006
		0.029		
		0.027		
	Van der Vossen 2005	0.027		
		0.022		
Robusta	Harding 1992	0.017	0.012	0.005
		0.006		

4.2 Avocado

The nitrogen nutrient uptake referring to the whole plant is difficult to obtain. Data can only be found referring to nitrogen content in fruit. The nitrogen nutrient uptake by Avocado fruit was taken from Van Ee (1998).

Table 5: N-nutrient uptake by Avocado according to Van Ee 1998 (data refer to nitrogen uptake in fruit)

Nitrogen uptake (kg N/ha)	Yield (ton harvested crop/ha)	Nitrogen uptake (kg N/kg crop)
40	14.5	0.0027

4.3 Banana

The nitrogen nutrient uptake per kg banana was calculated on the basis of Martin-Prevel (1992) and Haifa (n.y.) (see Table 6). Data from Martin-Prevel refer to specific banana cultivar, while the other source relates to the nutrient uptake by general banana. The uptake ranges from 0.003 to 0.01 kg nitrogen per kg banana, the average value thus amounting to 0.006 kg N per kg harvested crop.

Table 6: N-nutrient uptake by Banana according to different sources

Cultivar	Nitrogen uptake (kg N /ha)	Bunch yield (ton/ha)	Nitrogen uptake (kg N/kg Crop) calculated
According to Haifa n.y.			
Unspecified	198	30	0.007
Unspecified	339	60	0.006
According to Martin-Prevel 1992			
Pisang Assam	40	16	0.003
Gros Michel	250	26	0.010

Cultivar	Nitrogen uptake (kg N /ha)	Bunch yield (ton/ha)	Nitrogen uptake (kg N/kg Crop) calculated
Dwarf Cavendish	225	42	0.005
Plantains average	203	40	0.005
Popoulou	370	44	0.008
Poyo, grand Nain	250	35-57	0.005
Robusta	450	50	0.009
Poyo	450	66	0.007
Grand Nain	293	69	0.004
Americani	294	75	0.004
Nanicao	264	77	0.003
Cavendish group	-	-	(0.004-0.007): Average: 0.0055
		Average value	**0.006**

4.4 Beans

Beans fix nitrogen gases from the air and convert them for use. The nitrogen source for green beans is often the air (FAO 2007). According to the availability of data, green beans are investigated in this study. FAO (2007) indicated that 80 kg of nitrogen nutrient is needed from the soil to achieve a yield of 12000 pods per hectare of bush green or yellow pods. To get a yield of 14000 pods/ha of pole bean, it needs 120 kg nitrogen nutrient from the soil (see Table 7).

Table 7: N-nutrient uptake from soil by beans according to FAO 2007

Type	Nitrogen uptake (kg N/ha)	Yield (t pods/ha)	Nitrogen uptake (kg N/kg pods)
Bush bean	80	12	0.007
Pole bean	120	14	0.009
		Average value	**0.008**

4.5 Citrus

Table 8 gives the nitrogen uptake by the citrus fruit. Similar to avocado, the nitrogen uptake by the whole plant is difficult to obtain. Data can only be found referring to nitrogen content in fruit.

Table 8: N-nutrient uptake by Citrus according to Van Ee 1998 (Data refer to the nitrogen uptake in fruit)

Nitrogen uptake (kg N/ha)	Yield (ton harvested crop/ha)	Nitrogen uptake (kg N/kg crop) calculated
44	24	0.002

4.6 Durian

Data on nitrogen uptake by durian is difficult to obtain. Therefore, we applied the second approach described in Chapter 3, intending to calculate the nitrogen uptake by using fertilizer consumption and the Nitrogen Use Efficiency (NUE). Sabri (2009) reported the nitrogen consumption by durian in Malaysia for the years 2002, 2007 and 2008 (c.f. Table 9). Ideally, the nitrogen uptake can be calculated if the *NUE* of durian in Malaysia is known. The NUE is also difficult to obtain. In this case, we assume that NUE accounts for 50% of the the fertilizer used by the crops, meaning that half of fertilizer used is absorbed by the durian plant and that losses account for the other half.

Therefore, it is concluded that 0.001 kg of nitrogen is taken up per kg durian.

Table 9: N-application by Durian according to Sabri 2009

Year	Estimated consumption of nutrients (ton N/a)	Crop area (ha/a)	Crop yield (kg/ha/a)	Nitrogen uptake (kg N/kg crop) calculated
2002	950	121568	3543	0.002
2007	890	106442	3500	0.002
2008	920	107507	3500	0.002
			Average	0.002
			Assumption: NUE (Nitrogen Use Efficiency) =	50%
			Average value	**0.001**

4.7 Maize

Table 10 gives the nitrogen uptake of grain maize.

Table 10: N-nutrient uptake by Maize according to different sources

Nitrogen uptake		Yield		Nitrogen uptake
Pounds / acre	**kg/ha**	**Bushel (bu.)/acre**	**tons/ha**	**kg N/kg crop**
According to Eastern Canada 2001				
170	190.4	150	10.09	0.019
240	268.8	150	10.09	0.027
According to Western Canada 2001				
138	154.6	-	6.27	0.025
168	188.2	-	6.27	0.030
According to Hoeft 1992				
-	220	-	11.80	0.019
			Average	**0.024**

4.8 Mango

Two sources were found. Peter (2007) cited the results from another study by Devi and Mruthunjaya (2000), indicating that nitrogen nutrient uptake by mango tree amounts to 165 kg for a crop yield of 25 t/ha.

Table 11: N-nutrient uptake by Mango according to different sources

Nitrogen uptake (kg N/ha)	Yield (ton harvested crop/ha)	Nitrogen uptake (kg N/kg crop) calculated
According to Devi and Mruthunjaya 2000, cited by Peter 2007		
165	25	0.007
	Average	**0.007**

4.9 Papaya

The nitrogen nutrient uptake referring to the whole plant is difficult to obtain. Data can only be found referring to nitrogen content in fruit. Table 12 provides data on the nitrogen uptake of papaya.

Table 12: N-nutrient uptake by Papaya according to Van Ee 1998 (Data refer to the nitrogen uptake in fruit)

Nitrogen uptake (kg N/ha)	Yield (ton harvested crop/ha)	Nitrogen uptake (kg N/kg crop) calculated
35.4	20	0.002

4.10 Pepper

The following table is directly taken from the Ann 2012b, in which the nitrogen nutrient uptake of pepper was investigated over 30 months. The total nitrogen accumulated by plant amounts to 293.08 kg per hectare.

Table 2 Major nutrient accumulation and distribution (kg ha^{-1}) in various parts of pepper vines, over 30 months period at Sg. Udang, Melaka

Nutrient	Plant parts	Months after planting 2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	Net accumulation
N	Leaves	0.13	0.58	2.25	6.78	10.75	16.3	26.75	46.06	67.89	78.62	73.57	64.88	58.34	67.95	73.87	73.87
	Stem	0.12	0.51	1.41	4.52	9.01	14.38	21.35	29.83	39.75	47.93	42.66	44.12	46.78	52.38	60.57	60.45
	Branches	0.03	0.28	0.71	2.84	6.54	11.97	23.42	30.98	38.86	48.52	46.86	45.07	34.4	41.25	45.87	45.84
	Root	0.07	0.31	0.83	1.66	2.04	3.82	5.71	7.43	9.26	10.74	12.01	12.34	13.2	13.98	14.22	14.15
	Flower	/	/	/	/	/	/	/	/	2.58	7.76	/	/	/	/	/	7.76
	Spike	/	/	/	/	/	/	/	/	/	2.62	4.42	3.64	4.22		/	4.22
	Fruit	/	/	/	/	/	/	/	/	/	19.49	28.75	51.04	86.79		/	86.79
	Total plant	0.35	1.68	5.2	15.8	28.34	46.47	77.23	114.3	158.3	215.6	208.2	221.0	257.7	175.5	194.5	293.08

However, the yield value is not mentioned in this study. We found another similar study with a different investigation focus, namely Ann (2012a) in which the yield value is reported. The yield of dry pepper berries amounts to 5.74 t/ha. What is also needed for the conversion from dry berries to fresh berries is the conversion factor. About 11230 kg/ha of green berries are converted to 3930 kg/ha of dried black pepper (Nelson & Cannon-Eger 2011). Hence, 5.74 t/ha of dry pepper corresponds to 16.4 t of fresh berries.

Table 13: N-nutrient uptake by Pepper derived from Ann 2012b, Ann 2012a and Nelson & Cannon-Eger 2011

Nitrogen uptake (kg N/ha)	Yield (ton harvested crop/ha)	Nitrogen uptake (kg N/kg crop) calculated
293.08	16.40	0.018

4.11 Plantain

According to Rosales et al. (2010), the nitrogen uptake by a plantain plant amounts to 107 g per plant. However, there is no description of the yield per plant. Banana and Plantain belong to the Musa species (Musaceae). Given the data submitted in the chapter of banana, the nitrogen uptake of banana varies considerably depending on the cultivars. Due to a lack of data on plantain, the nitrogen uptake of plantain is assumed to be at the same level as that of banana.

5 Recommendation of default values of nitrogen uptake as allocation parameters

The calculated default values of nitrogen uptakes are summarised below. Average values are used where there is more than one data source available. For coffee, a standard deviation is given based on the data available within the framework of this study, as more than one source is available. EPD practitioners may use this figure in order to carry out a sensitivity analysis. Regarding other crops, standard deviation cannot be built due to the lack of sources. To keep consistency, merely average values of other crops are used.

Table 14: Recommended default values of nitrogen uptake as allocation parameters for Arabica coffee in intercropping systems

Intercropping system	Coffee (kg N / kg coffee cherry)	Other cash crop (kg N / kg crop)
Arabica Coffee - Avocado*	0.023±0.006	0.003
Arabica Coffee - Banana	0.023±0.006	0.006
Arabica Coffee - Bean (green)	0.023±0.006	0.008
Arabica Coffee - Citrus*	0.023±0.006	0.002
Arabica Coffee - Durian**	0.023±0.006	0.001
Arabica Coffee - Maize	0.023±0.006	0.024
Arabica Coffee - Mango	0.023±0.006	0.007
Arabica Coffee - Papaya*	0.023±0.006	0.002
Arabica Coffee - Pepper	0.023±0.006	0.018
Arabica Coffee - Plantain	0.023±0.006	0.006

* Data on avocado, citrus and papaya refer to the nitrogen uptake in the fruit itself, due to lack of data on nitrogen uptake in the whole plant.

** Data on durian is calculated based on fertilizer application and Nitrogen Use Efficiency (NUE) assumed as 50%.

Table 15: Recommended default values of nitrogen uptake as allocation parameters for Robusta coffee in intercropping systems

Intercropping system	Coffee (kg N / kg coffee cherry)	Other cash crop (kg N / kg Crop)
Robusta Coffee - Avocado*	0.012±0.005	0.003
Robusta Coffee - Banana	0.012±0.005	0.006
Robusta Coffee - Bean (green)	0.012±0.005	0.008
Robusta Coffee - Citrus*	0.012±0.005	0.002
Robusta Coffee - Durian**	0.012±0.005	0.001
Robusta Coffee - Maize	0.012±0.005	0.024
Robusta Coffee - Mango	0.012±0.005	0.007
Robusta Coffee - Papaya*	0.012±0.005	0.002

Intercropping system	Coffee (kg N / kg coffee cherry)	Other cash crop (kg N / kg Crop)
Robusta Coffee - Pepper	0.012±0.005	0.018
Robusta Coffee - Plantain	0.012±0.005	0.006

* Data on avocado, citrus and papaya refer to the nitrogen uptake in the fruit itself, due to lack of data on nitrogen uptake in the whole plant.

** Data on durian is calculated based on fertilizer application and Nitrogen Use Efficiency (NUE) assumed as 50%.

It should be stressed that the calculation of allocation ratios has to be done taking the yield of crops into consideration. Since the yield of intercropping systems might vary largely according to different soil conditions or types of cultivation, it is essential to obtain data on the yield of intercrops when conducting individual EPDs. In this respect, it should also be pointed out that the fertilizers applied have to be specified, since different types of N fertilizers have different impacts on the GHG emissions resulting from production.

As described in the summary tables above, the data on avocado, citrus, and papaya refer to the nitrogen uptake in the fruit itself. Furthermore, nitrogen uptake by durian is calculated based on fertilizer application and Nitrogen Use Efficiency (NUE) assumed as 50%. This approach could lead to an underestimation of the proposed default values on these three crops due to lack of data on nitrogen uptake by the whole plant. It should be stressed that data have an uncertainty. However, concerning this PCR, coffee is the investigated object. According to ILCD handbook (2010), "Allocation shall however not be performed if it would relevantly favour the analysed process / system." We hope that there will be more published studies and research in three years, as the PCR has a validity of three years and will then be updated.

It should be stressed that the default value table is intended for those practitioners, who do not have any primary data. We therefore suggest checking the following steps for allocation rules for the fertilizer use in the polyculture system:

The approach towards allocation shall be conducted in a hierarchy:

a) Break down the process into sub-processes and collect the primary data on e.g. fertilizers used for coffee and for other cash crop.
b) If it is not possible to collect data on the quantities of fertilizers for all crops in the analysed system, the farmers should be encouraged to estimate at least the data on coffee. They know how many coffee trees they have and should also know roughly how much fertiliser they use for each tree, as these fertilisers are applied manually in a ring around the tree stem.
c) If practitioners have other literature sources, which are evaluated as of higher quality or have more representative data for the individual coffee investigated than the default value tables provided, these data sources are encouraged to be used.

d) If the above steps are not feasible, the proposed default values can serve as a basis for allocation.

Example for use of the default value listed in Tables 14 and 15 and to calculate the allocation ratio: Coffee–banana intercropping system

Primary data (also called specific data) from the survey on the farm contains the following information (*NOTE: Numbers below are purely fictive)*:

- Farm A only knows that it purchases 1000 kg of total nitrogen fertilizers per year for their Arabica coffee and banana intercropping system.
- The average yield of coffee cherries is 800 kg/a; the average yield of banana is 500 kg/a.

The EPD practitioners can use the above data and default values listed in the PCR to easily calculate the allocation ratios as follows:

- The individual nitrogen requirement of coffee and banana per year can be calculated based on the amount of crops needed (default value see Table 14) and the specific yield of the crops from the primary data

$$Coffee: \frac{0.023 kg\ N}{kg\ Coffee\ cherry} x\ 800 \frac{kg}{a} = 18.4 kg\ N/a$$

$$Banana: \frac{0.006 kg\ N}{kg\ Banana} x\ 500 \frac{kg}{a} = 3 kg\ N/a$$

  The results show that coffee needs 18.4 kg of nitrogen fertilizers per year to harvest 800 kg coffee cherries, and banana needs 3 kg to harvest 500 kg banana.

- The second step is to calculate the percentage of allocation ratios assigned between coffee and banana.
- Percentage of Arabic coffee: $\frac{18.4}{(18.4+3)} = 86\%$
- Percentage of banana: $\frac{3}{(18.4+3)} = 14\%$
- That means that of 1000 kg of total nitrogen fertilizers applied on this farm, 860 kg will be assigned to coffee (86%) and 140 kg to banana (14%) per year.

Note: The calculated amount of fertilizers might not be equal to the actual amount applied on the farm. This might, e.g., be based on the fact that the farmer applied additional organic compost or manure.

6 Annex

Additional Excel tables are provided as separate Excel file, setting out the detailed information on which the calculation is based.

7 Literature

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