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Effects of Plant Density and Delayed Bean Sowing on Yields, Economic and Nutritional Perfomances of Cassava-Maize-Bean Intercrops: A Case Study in Kirimiro and Mumirwa Agro-ecological zones, Burundi

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ABSTRACT

Cassava-maize-bean intercropping systems testing effects of spacing (plant density) and bean planting date were assessed under two major Burundi agro-ecological zones (AEZ), Mumirwa and Kirimiro. Evaluated spacing for all three tested crops were as follows: recommended spacing (RS), RS+20 % and RS + 40 %. Bean was planted either at the same time as other two crops or with a 3-week delay. Measured parameters were intercrops' and total yields, nutrient value (energy, proteins) and economic benefits (gross monetary values, total costs, net returns and value/cost ratio -V/C). Over all measured parameters, bean contributed more in the Kirimiro AEZ, while cassava contributed more in the Mumirwa AEZ. In the Mumirwa AEZ, cassava represented 82 % of the total yields, while bean and maize represented only 11 and 7 %, respectively. In the Kirimiro AEZ, comparative figures were 54 % for cassava, 33 % for bean and 13 % for maize. Cassava represented 64 % of the total energy yields in the Mumirwa AEZ and 20% for maize and 16 % for bean. In the Kirimiro AEZ, similar figures were 34 % for cassava, 46 % for bean and 20 % for maize. Bean contributed 77 % of the total proteins when all three crops were installed at the same time, whereas maize brought in 10 % and cassava 13 % of proteins, respectively. Bean generated 23 % more money in the Kirimiro AEZ while cassava yielded three-times more money in the Mumirwa AEZ. Overall, revenues generated through the cassava + maize + bean intercropping was two times higher in the Mumirwa than in the Kirimiro AEZ. In the Kirimiro AEZ, bean contributed for 60 % of the total monetary values and only 27 % in the Mumirwa AEZ. A similar reflexion applied to cassava indicated that it contributed to the crop yield global monetary value for 67 % in the Mumirwa AEZ and only 30 % in the Kirimiro AEZ. Maize monetary contribution to the global monetary values was 10 % in the Kirimiro AEZ and 6 % in the Mumirwa AEZ. Maize contribution across AEZ was almost insignificant because of its low yields and practiced selling prices. With a V/C ratio of 2.42, the cassava + maize + bean intercropping system was more profitable in the conditions of the Mumirwa AEZ. In the Kirimiro AEZ bean production was 60 % higher when planted at the same time as other crops than when delayed for three-weeks. Similar tendancies were observed for returns (+ 72 %), V/C (+ 34 %), energy (+ 60 %) and proteins (+ 60 %) yields. On the opposite, bean 3-week delay favored maize yield (+ 42 %), energy and proteins yields (+ 42 %). The same trends in agronomic, economic and nutritional values was also observed in the Mumirwa AEZ with lower bean and maize productions but higher cassava yields. In conclusion, all in all, more returns (+ 36 %) were obtained when all three crops were sown/planted at the same time with a V/C ratio = 2.36. In parallel, effect of crop density/spacing indicated that recommended crop spacing increased by 20 % (RS + 20 %) was more economically profitable (V/C=2.39).

Keywords: Cassava, Maize, Bean, Intercropping, Planting Date, Spacing, Yields, Returns, Energy, proteins.

1. INTRODUCTION

Multiple cropping/intercropping can be double (maize-bean, banana-bean), triple (banana-maize-bean, cassava-maize-bean) or more complex (banana-cassava-maize-bean; cassava-maize-soybean-cowpea) [1]. Cereal-legume systems are the predominant cropping systems in Burundi, in East Africa and in so-called developping countries for a number of reasons [2-10]. The targeted objectives odf such complex plant arrangements and densities are the following: (i) reduce the risk of harvest loss following rainfall deficit; (ii) improve intensive use of small land area and family labor force; (iii) provide higher income and diversified diets; ecological intensification and reduction of climatic risks [10,11].

These extended benefits of the intercropping systems include land productivity and yield stability, nutrition and food security, soil conservation, global crop resilience, environment health in terms of soil, water and air quality, bio-remediation (phytoremediation), increased use of solar radiation, water use efficiency due to decreased evaporation, increased nutrient uptake, decreased weeds pressure and subsequently weeding labor investment, mitigating climatic change, C-sequestration and global warming mitigation, microbial abundance and diversity. All the above benefits leading to sustainable agriculture [12].

Otherwise, every single farmer ultimate's aim the production of food with equilibrated contents in energy, proteins, essential aminoacids, vitamins and mineral [13]. When different cropping systems are compared on an economic and nutritional rather than an agronomic/biological basis, added values of such systems are evaluated using a common measurement unit. Hence, quality differences of the products are considered and, above all, both researchers, farmers as well as the common consummers speak and understand the same language.

Economic evaluation of intercropping admits that the farmer makes a rationnal choice among cropping systems based on potential net returns. However, this economic approach shows some limitations. Given that intercropping systems are a prototype of subsistance agriculture, a model which does always follow market prices, added to the fact that such prices vary in space and time, hence making unrealistic transversal comparisons [13,14].

In the socio-economic context outlined above, ADISCO and UPH opted to work together with farmers. Consequently, its research team is able to get a better understanding of what the farmer/partner is facing and from there on a strictly participatory way come up with practical and consensual solutions. The principal motivation of ADISCO and UPH's investigation comes from the empirical observation that a significant proportion of Burundian farmers relies on multiple cropping for their food security and nutrition. Through indigenous know-how transmitted from generations to generations, it is apparent that Burundian farmers adopted often complex cropping systems and combinations which require a better understanding of their functionning and rationale. Burundi scientists have the responsibility to evaluate and improve them if needed [13,14].

The present research study is a follow-up of a previous investigation on comparative advantages of cassava + maize + bean intercrops relative to their respective monocrops [13]. This specific study concluded that, in short tem, for most farmers, obtaining a well-balanced and regular diet for their family is more meaningful than any other intercropping benefits. The global objective of the present investigation was to evaluate the advantages of the cassava-maize-bean intercropping system, relative to plant densities and bean planting delay under two major Burundi agro-ecological zones (AEZ), Mumirwa and Kirimiro. Specifically, the different intercropping systems were assessed based on their effects on intercrops and total yields, nutrient value (energy, proteins) and economic benefits (gross monetary values, total costs, net returns and value/cost ratio -V/C).

2. MATERIALS AND METHODS

2.1 Sites description

As for the first ADISCO and UPH initiated study on cassava-maize-bean intercropping [13], the present investigation was conducted on plots provided by selected collaborative volunteer farmers in Kirimiro and Mumirwa agro-ecological zones. Both sites are characterized by a bimodal rainfall distribution with a long rainy season from february to may and a short rainy season from september to december. The two rainy seasons are separated by a short dry season from mid-december to mid-january, and a long dry season from june to august. Mean annual rainfall is 932 mm in the Mumirwa site and 1,527 mm in the Kirimiro site. Average annual temperature is respectively 24°C in Mumirwa and 21°C in Kirimiro [15].

2.2 Soils

This study on cassava-maize-bean intercropping agronomic, economic and nutrionnal performances was conducted on same types of soils as the previous study [13]. Soil characteristics are the same as those documented in the study previously published in the International Journal of Advances in Scientific Research and Engineering, Volume 6, Issue 4 (135-150) [13].

2.2 Planting materials and fertilization

Crop varieties used were those recommended by the Burundi Agriculture Research Institute (ISABU) in the particular agro-ecological zones: Muhoro (1,200-1,500 m; 2.25 T/ha) for climbing beans (*Phaseolus vulgaris* L.), ZM 605 (1,200-1,800 m; 3.5-4.5 T/ha) for maize (*Zea mays* L.) and Ngarukiye (1,600 m; 25-40 T/ha) for cassava (*Manihot esculenta* Crantz) in both regions. Similarly, fertilizer applications on the three crops referred to research recommendations [16].

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Bean (Phaseolus vulgaris L.) received 100 kg of DAP, 50 kg of KCl per ha equivalent to 150 kg FOMI Imbura (N-P_2O_5-K_2O-Ca-Mg: 9-22-4-13-2), completed with an equivalent of 10 T/ha of farm manure. At least 2 weeks before planting maize (*Zea mays* L.), an equivalent 750 kg/ha of dolomitic lime was broadcasted followed by an application of 130 kg of DAP per ha and 50 kg KCl per ha at planting, 18.5 kg of urea at the first weeding (20 days after planting) and 28.5 kg per ha at hilling. Alternately, 270 kg/ha of FOMI Imbura combined with 100 kg per ha of FOMI Totahaza (N-P_2O_5-K_2O-Ca-Mg: 21-0-8-4-2) could be used in replacement of the DAP, KCl and Urea combination. Cassava (*Manihot esculenta* Crantz) received 3 T/ha of dolomitic lime two weeks before planting. Both intercrops received an equivalent of 10 T/ha of cow manure two weeks before planting. Maize (*Zea mays* L.) weeding was done 3 weeks after planting. Hoeing was done after 6 weeks and hilling was executed at flowering.

Under the intercropping system under investigation, climbing bean (*Phaseolus vulgaris* L.) crop was planted 40 cm x 20 cm with 70 cm between double rows based on recommended plant spacing (RS). When bean (*Phaseolus vulgaris* L.) spacing was increased by 20 and 40 %, the forefront dimensions became 48 cm x 24 cm with 84 cm between double rows [RS + (RS*20 %)] and 56 cm x 28 cm with 98 cm between double rows [RS + (RS*40 %)]. Maize (*Zea mays* L.) was planted at 75 cm x 50 cm spacing (26,667 plants/ha) adjusted to 90 cm x 60 cm (18,518 plants/ha) and 105 cm x 70 cm (13.605 plants/ha) when densities were reduced by 20% and 40 %, respectively. Cassava (*Manihot esculenta* Crantz), spacing was 1 m x 1 m (10,000 plants/ha) under recommended density, 1.2 m x 1.2 m (6,944 plants/ha) and 1.4 m x 1.4 m (5,102 plants/ha) when densities were reduced by 20 and 40 % (or else spacing was increased by 20 and 40 %), respectively.

In Mumirwa (Bubanza province), the experiments were installed during season 2021A on october 22-23, 2020. The second bean (*Phaseolus vulgaris* L.) crop was installed on 6 and 9 march, 2021. Bean (*Phaseolus vulgaris* L.) crop was harvested at different periods depending on its planting time. Bean (*Phaseolus vulgaris* L.) crop planted at the same time as cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) was harvested on January 18-20, 2021. Maize (*Zea mays* L.) crop and three-week delay bean (*Phaseolus vulgaris* L.) planted were harvested on February 18-19, 2021. The sole cassava (*Manihot esculenta* Crantz) crop was harvested on September 15-17, 2021. In Kirimiro, experimental plots were put in place on October 27-29, 2020. The second bean (*Phaseolus vulgaris* L.) crop was installed on 4 and 5 march, 2021. Bean ((*Phaseolus vulgaris* L.) crop planted at the same time as cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) was harvested on February 10-11, 2021. Maize (*Zea mays* L.) crop and three-week delay bean (*Phaseolus vulgaris* L.) planted was harvested on 3-5 march, 2021.

2.3 Experimental Design

The twin experiments were conducted in both Kirimiro and Mumirwa agro-ecological zones (AEZ) in a completely randomized bloc design [17] with four replicates (farmers) in each AEZ. Each farmer plot of 20 m x 14 m is considered a bloc (repetition). Each bloc (farmer plot) was divided in six experimental units of 6 m x 6 m (harvested area) to which 6 treatments were assigned. The 6 treatments were as follows:

T_1: Cassava, maize and bean planted at the same time in alternate lines with recommended respective plant spacing (RS) in monocropping systems

T_2: Cassava, maize and bean planted at the same time in alternate lines with recommended respective plant spacing (RS) in monocropping systems increased by 20 % [RS + (RS*20 %)]

T_3: Cassava, maize and bean planted at the same time in alternate lines with recommended respective plant spacing (RS) in monocropping systems increased by 40 % [RS + (RS*40 %)]

T_4: Cassava and maize planted at the same time followed by bean three weeks after. Plantations in alternate lines with recommended respective plant spacing (RS) in monocropping systems.

T_5: Cassava and maize planted at the same time followed by bean three weeks after. Plantations in alternate lines with recommended respective plant spacing in monocropping systems increased by 20 % [RS + (RS*20 %)]

T_6: Cassava and maize planted at the same time followed by bean three weeks after. Plantations in alternate lines with recommended respective plant spacing in monocropping systems increased by 40 % [RS + (RS*40 %)]

2.4 Measured Parameters

Evaluated parameters included intercrops yields and their total, monetary values, total costs, net returns, nutritive values (energy and proteins content) of the respective productions in cassava (*Manihot esculenta* Crantz), maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) intercrops, together with their economic efficiency (V/C).

2.4.3 Nutrient Value

With the undeniable principle that most subsistence farmers in developping countries aspire to ensure food and nutrition security for their families [13,14], we evaluated the comparative nutrive benefits of cassava-maize-bean intercrop based on FAO standards [18]. Such an exercice generated energy (kilocalories/ha) and protein (kg/ha) data summarized in Tables 4b and 4c.

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Respective protein contents of 100 g of produce is 22.6 g for bean (*Phaseolus vulgaris* L.), 9.3 g for maize (*Zea mays* L.) and 1.2 g for cassava (*Manihot esculenta* Crantz). The same quantity (100 g) of products provides 333 kilocalories for bean (*Phaseolus vulgaris* L.), 353 kilocalories for maize (*Zea mays* L.) flour and 149 kilocalories for fresh cassava (*Manihot esculenta* Crantz) [18].

The abovementionned FAO standards were used to calculate energy and protein values of tested crops in intercropping systems. Generated data through the application of Equations 1 and 2 intercrop yields are shown in 2b and 2c.

Total Energy (kcal/ha) = (Y_c x E_c) **(1)**

Total Proteins (kg/ha) = (Y_c x P_c) **(2)**

Where Yc = Yield (kg/ha) for Crop "c" (bean, maize, cassava)

Ec and Pc = Energy (kcal/kg of produce) and protein (kg of proteins /kg of produce) [35].

2.4.4 Economic Benefits

Comparative economic profitability of intercropped systems as evaluated based on yields scaled up to as per hectare. For that purpose, gross and net returns and economic efficiency were calculated according to equations 3, 4 and 5.

Total return/ha = (yield A x price A) + (yield B x price B) + (yield C x price C) **(3)**

Net return/ha = total return – variable costs in intercrops crops **(4)**

Economic performance of the cropping systems = V/C ratio **(5)**

Where, V = monetary value and C = total costs. Any investment is considered profitable when its V/C > 2 [19].

In Mumirwa, practiced prices per kg of produce were 1.800 BIF for bean (**A**), 680 BIF for maize (**B**) and 600 BIF for fresh cassava (**C**) in accordance with the 2020-2021 market prices. In Kirimiro, selling prices for bean, maize and fresh cassava were 1600, 680 and 500 BIF, respectively. Conversion to US currency can be made using the rate USD = 2025 BIF.

2.5 Statistical Analyses

The experimental design was three-factor (AEZ, Bean Planting Date and Density) randomized bloc with 4 replicates. Bean (Phaseolus vulgaris L.) planting was performed either at the same time as cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) or three-weeks after. The latter practice is very common in Burundi agriculture systems, particularly in Season A (September-February).

Measured parameters included intercrops yields and their summation, monetary values, total costs, net returns, economic efficiency (V/C ratio), as well as energy and proteins yields. They were subjected to an analysis of variance (Anova 3) using R Studio Statistical Package [20]. When statistical significance was observed, mean separation was performed with the Newman-Keuls method based on the Least Significant Difference (LSD) [17].

3. RESULTS AND DISCUSSION

3.1 Yields

A three-criteria analysis of variance on intercropped cassava (*Manihot esculenta* Crantz), maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) yields is summarized in Table 1a. The analysis highlights the absence ($p > 0.05$) of any effect of plant density and the two- and three-way interactions of evaluated factors, i.e agro-ecological zone, bean planting date and plant density. However, significant effects of AEZ on bean ($p < 0.001$), cassava ($p < 0.001$) and total yields ($p < 0.001$) were observed, together with effects of bean planting date on bean ($p < 0.001$) and maize ($p < 0.01$) yields. No statistical effect of AEZ on maize (*Zea mays* L.) yields was observed, as well as the effect of planting date on cassava (*Manihot esculenta* Crantz) and total yields (($p > 0.05$).

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Data shown in Table 1b to 1c concern only those for which statistical analysis showed significant effects of tested parameters.

Table 1a. Three-criteria analysis of variance (Anova 3) on intercrop's yields (kg/ha)

Factor	Bean	Maize	cassava	Total
AEZ	***	NS	***	***
Bean Planting Date (BPD)	***	**	NS	NS
Density/Spacing	NS	NS	NS	NS
AEZ x Bean Planting Date (BPD)	NS	NS	NS	NS
AEZ x Density	NS	NS	NS	NS
Bean Planting Date (BPD) x Density	NS	NS	NS	NS
AEZ x Bean Planting Date (BPD) x Density	NS	NS	NS	NS

NS = Non significant ($p > 0.05$)
*** = Very highly significant ($p < 0.001$)
** = Highly significant ($p < 0.01$)
* = Simply significant ($p < 0.05$)

Table 1b. Effect of agro-ecological zones (AEZ) on bean and cassava intercrop components and total crop yields (kg/ha)

AEZ	Bean	Cassava	Total
Kirimiro	2445.6**a**	3952.5**b**	7387.2**b**
Mumirwa	1763.9**b**	12908.6**a**	15805.9**a**
LSD	381.3	2083.0	2074.1
Level of probability	***	***	***

Mean values with identical letters within the column are not statistically different at $p < 0.05$)

Table 1b shows significant effects of AEZ on bean (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta* Crantz) and total yields. Bean (*Phaseolus vulgaris* L.) yields were 39 % higher in Kirimiro than in the Mumirwa AEZ. On the contrary, cassava (*Manihot esculenta* Crantz) production was three-times higher in the Mumirwa AEZ than in the Kirimiro AEZ. When bean (*Phaseolus vulgaris* L.), maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz) productions were combined (total yields), we observe that the Mumirwa AEZ is associated with twice the total yields registered in the Kirimiro AEZ. However, no significant differences between maize (*Zea mays* L.) yields in the two AEZ were observed. Maize (*Zea mays* L.) yield in Kirimiro was about 989.1 kg/ha compared to 1133.4 kg/ha in Mumirwa, indicating very low maize (*Zea mays* L.) yields in the two AEZ during the growing season 2021A. This will translate in the low contribution of the commodity in returns, energy and proteins yields of the cassava-maize-bean intercopping system under the present investigation.

In relative terms, in the Mumirwa AEZ, cassava (*Manihot esculenta* Crantz) represents 82 % of the total yields, while bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) represent only 11 and 7 %, respectively. In the Kirimiro AEZ, comparative figures are only 54 % for cassava (*Manihot esculenta* Crantz), 33 % for bean (*Phaseolus vulgaris* L.) and 13 % for maize (*Zea mays* L.). This is an indication that cassava (*Manihot esculenta* Crantz) yielded higher in the Mumirwa AEZ, while bean (*Phaseolus vulgaris* L.) yielded proportionally higher in the Kirimiro AEZ. Figure 1 graphically illustrates such scenarios.

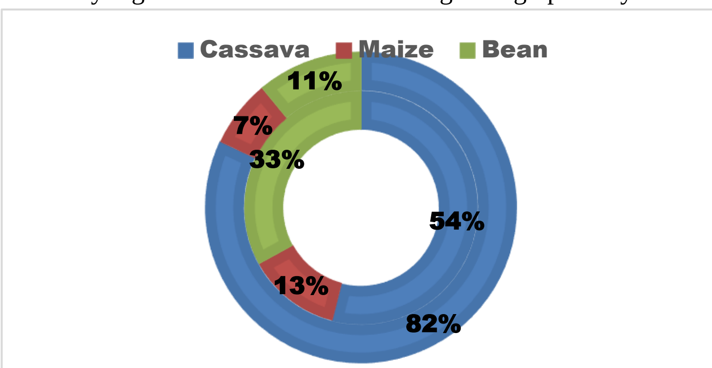

Figure 1. Proportionnal contribution (%) of cassava, maize and bean intercrops to total yields in Kirimiro (inner ring) and Mumirwa (outer ring) AEZ.

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Analysis of variance applied to bean (*Phaseolus vulgaris* L.) planting date (BPD) indicated significant effects of the factor on bean ($p < 0.001$) and maize ($p < 0.05$) yields. When bean (*Phaseolus vulgaris* L.) planting dates are compared, it appears that planting bean (*Phaseolus vulgaris* L.) at the same time as the other two crops (cassava and maize) yielded significantly higher (+ 60 %) than bean (*Phaseolus vulgaris* L.) sown 3-week after cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) across AEZ. On the opposite, bean (*Phaseolus vulgaris* L.) sown with a 3-week delay generated 37 % more maize (*Zea mays* L.) yields, as compared to the simultaneous three crop installation.

Table 1c. Effect of Bean Planting Date (BPD) on yields of bean and maize intercrop compoments (kg/ha)

Bean Planting Date	Bean	Maize
Same Time as other crops	2588.5**a**	894.4**b**
3-Week Delay	1620.9**b**	1228.0**a**
LSD	381.3	210.6
Level of probability	***	*

Mean values with identical letters within the column are not statistically different at $p < 0.05$)

Delaying bean (*Phaseolus vulgaris* L.) sowing by thre weeks favored maize (*Zea mays* L.) yields. This biological phenomenon of crop yield compensation was also recorded by Francis (1986, 1989) [24,25] and R.W. Willey et al., 1979, 1991[26, 27]. From this observation, the former investigator advanced that when interplanted species are in competition for the same limiting factor, a proportional increase in the yield of one species would cause a concomitant decrease in the yield of the other intercropped. Francis observation is rightly verified in our present investigation.

3.2 Nutrive value

As stated elsewhere [15], we have the conviction that the most realistic concept of evaluating the advantages of intercropping systems, particularly in the context of Burundi subsistence agriculture, should be nutrition-based. Needless to stress out that for most Burundian farmers, obtaining a well-balanced diet for their family is more meaningful than any other intercropping benefits.

Table 2a shows a three-criteria analysis of variance on intercropped cassava (*Manihot esculenta* Crantz), maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) yields. As for the crop yields, the analysis highlights the absence ($p > 0.05$) of any effect of plant density and the two- and three-way interactions of evaluated factors of energy yields. Significant effects of AEZ on bean ($p < 0.001$), cassava ($p < 0.001$) and total ($p < 0.001$) energy yields were noticed. Bean (*Phaseolus vulgaris* L.) planting date (BPD) significantly affected bean ($p < 0.001$) and maize ($p < 0.001$) energy contents, but not cassava and combined energy yields ($p > 0.05$).

Table 2a. Three-criteria analysis of variance (Anova 3) on intercrops' energy yield (kcal/ha)

Factor	Bean	Maize	Cassava	Total
AEZ	***	NS	***	***
Bean Planting Date (BPD)	***	***	NS	NS
Density/Spacing	NS	NS	NS	NS
ZAE x Bean Planting Date (BPD)	NS	NS	NS	NS
AEZ x Density	NS	NS	NS	NS
Bean Planting Date (BPD) x Density	NS	NS	NS	NS
AEZ x Bean Planting Date (BPD) x Density	NS	NS	NS	NS

Table 2b above is an illustration of the significant effects of AEZ ($p < 0.001$) on bean (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta* Crantz) and total energy yields of the evaluated intercrops.

Table 2b. Effect of agro-ecological zone (AEZ) on Energy Yield (kcal/ha)

AEZ	Bean	Cassava	Total
Kirimiro	8,143,854**a**	5,889,294**b**	17,349,775**b**
Mumirwa	5,873,750**b**	19,233,762**a**	29,908,533**a**
LSD	1,269,600	3,103,616	3,255,605
Level of probability	***	***	***

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Mean values with identical letters within the column are not statistically different at p < 0.05)

In agreement with the yields' effects, bean (*Phaseolus vulgaris* L.) produced more energy (+ 39 %) in the Kirimiro than in the Mumirwa AEZ. On the other side, due to the comparatively high cassava (*Manihot esculenta* Crantz) yields in the Mumirwa AEZ, more than 200 % energy was registered in the latter than in the Kirimiro AEZ. At the same time, for the same reason, total energy was 67 % higher in the Mumirwa AEZ as compared to the Kirimiro AEZ (Table 2b).

The same thinking approach applied to energy yields of intrecrops and their summation brings out that cassava (*Manihot esculenta* Crantz) represents 64 % of the total energy yields in the Mumirwa AEZ. In the same agro-ecological zone, bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) represent 20 and 16 %, respectively. In the Kirimiro AEZ, similar figures are 34 % for cassava (*Manihot esculenta* Crantz), 46 % for bean (*Phaseolus vulgaris* L.) and 20 % for maize (*Zea mays* L.). It appears that in the Kirimiro AEZ bean (*Phaseolus vulgaris* L.) contributes almost half of the energy produced in the context of our experiment, more than twice as much as the bean (*Phaseolus vulgaris* L.) energy contribution in the Mumirwa AEZ, where cassava (*Manihot esculenta* Crantz) remains the main source of energy.
Figure 2 shows a graphical illustration of the numerical values mentionned above.

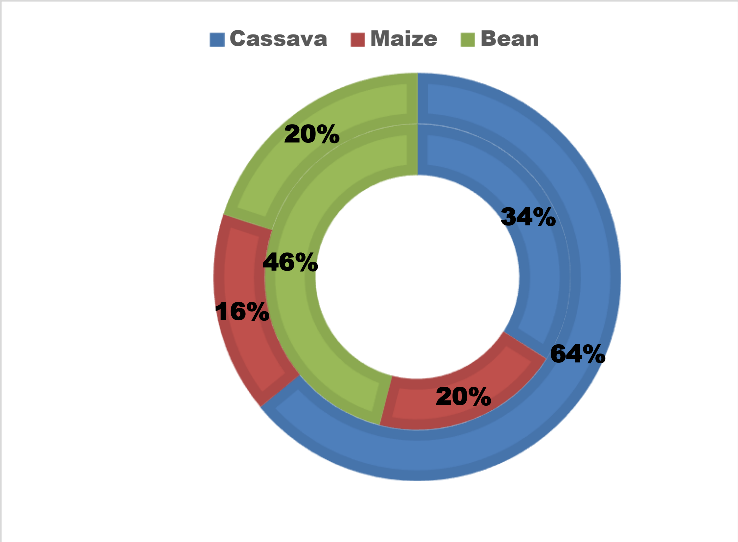

Figure 2. Proportionnal contribution (%) of cassava, maize and bean intercrops to total energy in the Kirimiro (inner ring) and the Mumirwa (outer ring) AEZ.

Analysis of variance performed on energy yield did not show any effect of bean (*Phaseolus vulgaris* L.) planting date (p > 0.05) on cassava (*Manihot esculenta* Crantz) and total energy. However, significant effects of bean planting date were observed on bean (p < 0.001) and maize (p < 0.05) energy yield. Table 4c indicates that planting intercrops at the same time increased bean energy (+ 60 %) more than the 3-week bean planting delay alternative. On the contrary, the latter option favored (+ 37 %) maize energy contribution.

Table 2c. Effect of Bean Planting Date on bean and maize intercrop compoments Energy Content (kcal/ha)

Bean Planting Date	Bean	Maize
Same Time as other crops	8,143,854**a**	2,999,519**b**
3-Week Delay	5,873,750**b**	4,118,129**a**
LSD	1,269,000	706,192
Level of probability	***	*

Mean values with identical letters within the column are not statistically different at p < 0.05)

Aside from energy yield as a nutritive parameter, protein content of tested intercropped cassava + maize + bean was statistically evaluated. Results obtained from the analysis are produced in Table 3a. They indicate significant effects of AEZ on bean (p < 0.001) and cassava (p < 0.001) proteins yields, and no effect on either maize or cassava + maize + bean proteins yield (p > 0.05). Bean planting date (BPD) statistically affected bean (p < 0.001), maize (p < 0.01) and the combination cassava + maize + bean as for proteins yields (p < 0.001).

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Table 3a. Three-criteria analysis of variance (Anova 3) on intercrops' protein yield (kg/ha)

Factor	Bean	Maize	Cassava	Total
AEZ	***	NS	***	NS
Bean Planting Date (BPD)	***	**	NS	***
Density/Spacing	NS	NS	NS	NS
AEZ x Bean Planting Date (BPD)	NS	NS	NS	NS
AEZ x Density	NS	NS	NS	NS
Bean Planting Date (BPD) x Density	NS	NS	NS	NS
AEZ x Bean Planting Date (BPD) x Density	NS	NS	NS	NS

Effects of AEZ on bean (*Phaseolus vulgaris* L.) and cassava (*Manihot esculenta* Crantz) protein yield are illustrated in Table 5b. Effects of bean (*Phaseolus vulgaris* L.) planting date (BPD) are shown in Table 3c.

Table 3b. Effect of agro-ecological zone (AEZ) on Protein Yields (kg/ha)

AEZ	Bean	Cassava
Kirimiro	552,706**a**	47,431**b**
Mumirwa	398,639**b**	154,903**a**
LSD	86,165	24,996
Level of probability	***	*

Mean values with identical letters within the column are not statistically different at p < 0.05)

Highest protein yields are observed in the Kirimiro AEZ for bean ($p < 0.001$) and in the Mumirwa AEZ for cassava ($p < 0.05$). Bean (*Phaseolus vulgaris* L.) yielded 39 % more proteins in the Kirimiro than in the Mumirwa AEZ, while cassava (*Manihot esculenta* Crantz) yielded more proteins (227 %) in the Mumirwa than in the Kirimiro AEZ. These tendencies follow these crop productions in the respectice AEZ.

Table 3c. Effect of Bean Planting Date on Protein Yields of bean/maize intercrop components and total yield (kg/ha)

Bean Planting Date	Bean	Maize	Total
Same Time as other cops	585,010a	79,024b	764,305a
3-Week Delay	366,335b	108,495a	576,892b
LSD	651,463	18,605	86,308
Level of probability	***	**	***

Mean values with identical letters within the column are not statistically different at p < 0.05)

Planting bean (*Phaseolus vulgaris* L.) at the same time as maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz) yielded more proteins (+ 60 %) for bean ($p < 0.001$) and cassava + maize + bean (+ 32 %) ($p < 0.001$). The opposite was noticed for maize (*Zea mays* L.), where 3-week bean (*Phaseolus vulgaris* L.) planting delay prevailed (+37 %) ($p < 0.01$).

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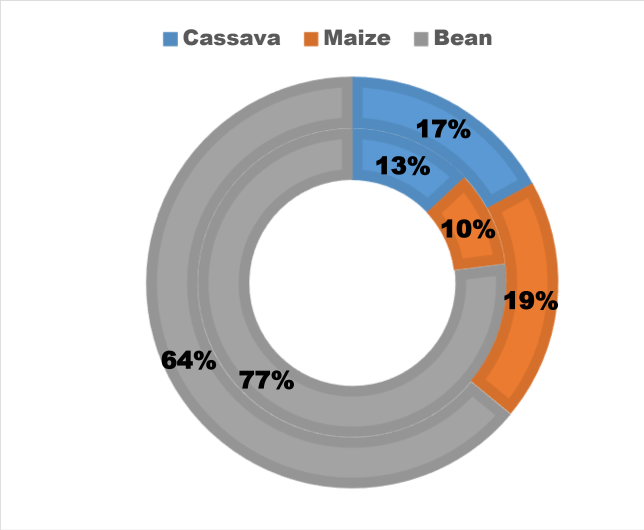

Figure 3. Proportionnal contribution (%) of cassava, maize and bean intercrops to total proteins when all crops are installed at the same time (inner ring) and with a 3-week bean planting delay (outer ring).

Proportionnally speaking and across AEZ and Planting densities, bean (*Phaseolus vulgaris* L.) contributes 77 % of the total proteins when all three crops are installed at the same time, whereas maize (*Zea mays* L.) brings in 10 % and cassava (*Manihot esculenta* Crantz) 13 % of proteins, respectively. In case the bean (*Phaseolus vulgaris* L.) crop is sown 3-week after cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) crops, bean (*Phaseolus vulgaris* L.) contribution is reduced to 64 %, when maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz) contribute for 19 % and 17 % of proteins, respectively. Bean (*Phaseolus vulgaris* L.) produces more proteins when sown at the same time as cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) crops. On the contrary, maize (*Zea mays* L.) produced more proteins when bean (*Phaseolus vulgaris* L.) is sown 3-week later.

Figure 3 depicts the respective cassava (*Manihot esculenta* Crantz), maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) protein contribution (%) to the intercropping system under the two bean (*Phaseolus vulgaris* L.) planting scenarios. Three-week bean delayed planting benefited maize (*Zea mays* L.) protein contribution. As was the case for maize (*Zea mays* L.) yield (Table 1c).

3.3 Economic Benefits

Set aside the nutrional benefit of intercropping, the most crucial advantages to farmers are based on comparative monetary values of the intercropping systems under study [13,14]. Analysis of variance performed on bean (*Phaseolus vulgaris* L.), maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz) and the cassava + maize + bean monetary values is shown in Table 4a, from which Tables 4b and 4c are generated. Effect of planting density was not significant ($p > 0.05$). However, significant effects of AEZ were observed with bean ($p < 0.05$), cassava ($p < 0.001$) and the cassava + maize + bean combination ($p < 0.001$). On the other hand, bean (*Phaseolus vulgaris* L.) planting date (BPD) significantlty affected bean ($p < 0.001$) and maize ($p < 0.01$) and total monetary values ($p < 0.05$).

Table 4a. Three-criteria analysis of variance (Anova 3) on intercrop's monetary values (Fbu/ha)

Factor	Bean	Maize	Cassava	Total
AEZ	*	NS	***	***
Bean Planting Date (BPD)	***	**	NS	*
Density/Spacing	NS	NS	NS	NS
AEZ x Bean Planting Date (BPD)	NS	NS	NS	NS
AEZ x Density	NS	NS	NS	NS
Bean Planting Date (BPD) x Density	NS	NS	NS	NS
AEZ x Bean Planting Date (BPD) x Density	NS	NS	NS	NS

A three-factorial analysis of variance (Anova 3) did not show any effect of agro-ecological zone (AEZ) on maize monetary value ($p > 0.05$). A similar analysis performed on bean, cassava and bean + maize + cassava indicated significant effect of the AEZ factor on bean ($p < 0.05$), cassava ($p < 0.001$) and global monetary values ($p < 0.001$).

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Table 4b. Effect of agro-ecological zones (AEZ) on monetary value of bean, cassava intercrops and total crop yields (Fbu/ha).

AEZ	Bean	Cassava	Total
Kirimiro	3,912,963**a**	1,976,273**b**	6,561,759**b**
Mumirwa	3,175,000**b**	7,745,139**a**	11,690,884**a**
LSD	651,463	1,217,191	1,236,707
Level of probability	*	***	***

Mean values with identical letters within the column are not statistically different at p < 0.05)

A three-factorial analysis of variance (Anova 3) did not show any effect of agro-ecological zone (AEZ) on maize (*Zea mays* L.) monetary value ($p > 0.05$). A similar analysis performed on bean, cassava and bean + maize + cassava indicated significant effect of the AEZ factor on bean ($p < 0.05$), cassava ($p < 0.001$) and global monetary values ($p < 0.001$).

Bean generated 23 % more money in the Kirimiro AEZ while cassava yielded three-times more money in the Mumirwa AEZ. Overall, money generated through the cassava + maize + bean intercropping was two times higher in the Mumirwa than in the Kirimiro AEZ. In the Kirimiro AEZ, bean (*Phaseolus vulgaris* L.) contributed for 60 % of the total monetary values and only 27 % in the Mumirwa AEZ. A similar reflexion applied to cassava (*Manihot esculenta* Crantz) indicates that the former crop contributed to the crop yield global monetary value for 67 % in the Mumirwa AEZ and 30 % in the Kirimiro AEZ. Maize (*Zea mays* L.) monetary contribution to the global monetary values was 10 % in the Kirimiro AEZ and 6 % in the Mumirwa AEZ. Maize (*Zea mays* L.) contribution across AEZ was almost insignificant because of its low yields and practiced selling prices. Bean (*Phaseolus vulgaris* L.) contributed more in the Kirimiro AEZ, while cassava (*Manihot esculenta* Crantz) contributed more in the Mumirwa AEZ.

Table 4c shows bean, maize and cassava + maize + bean monetary values across the two bean planting approaches: simultaneous planting of all three crops and the 3-week delay option.

Table 4c. Effect of Bean Planting Date on monetary value of bean and maize intercrop components and total yield (Fbu/ha)

Bean Planting Date	Bean	Maize	Total
Same Time as other crops	4,358,102a	680,222b	9,706,764a
3-Week Delay	2,779,861b	835,046a	8,455,880b
LSD	651,463	143,197	1,236,707
Level of probability	***	**	*

Mean values with identical letters within the column are not statistically different at p < 0.05)

Sowing bean (*Phaseolus vulgaris* L.) at the same time as cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) crop installation generated 60 % more monetary values to the produces. Under similar conditions maize (*Zea mays* L.) generated 23 % higher monetary values when bean (*Phaseolus vulgaris* L.) sowing was delayed for three weeks. Overall, it would be economically rewarding (+ 15 %) when all three crops are installed at the same time (Treatments T_1, T_2 and T_3).

Moneteray values alone do not mean much from an analytical and economical point of the wiew. For any entrepreunarial activity, what counts more are returns (monetary value – costs). Table 5a below show the statistical effects of tested parameters and their 2- and 3-way interactions. AEZ significantly affected ($p < 0.001$) costs, returns and V/C ratios. And so did bean's sowing date parameters on costs ($p < 0.001$), returns ($p < 0.05$) and V/C values ($p < 0.05$). The density parameter had a statistical influence on costs ($p < 0.001$) and V/C ratios ($p < 0.05$) and not on returns ($p > 0.05$).

Table 5a. Three-criteria analysis of variance (ANOVA 3) on total costs, total returns and V/C ratio

Factor	Costs (Fbu/ha)	Returns (Fbu/ha)	V/C
AEZ	***	***	***
Bean Planting Date (BPD)	***	*	**
Density/Spacing	***	NS	*
AEZ x Bean Planting Date (BPD)	NS	NS	NS

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AEZ x Density	NS	NS	NS
Bean Planting Date (BPD) x Density	NS	NS	NS
AEZ x Bean Planting Date (BPD) x Density	NS	NS	NS

Table 5b shows the statistically significant effects of AEZ on costs ($p < 0.05$), returns ($p < 0.001$) and V/C ratios ($p < 0.001$).

Table 5b. Effect of agro-ecological zone (AEZ) on Total Costs (Fbu/ha), Returns (Fbu/ha) and V/C ratio

AEZ	**Costs**	**Returns**	**V/C**
Kirimiro	3,569,859**b**	2,991,900**b**	1.87**b**
Mumirwa	4,927,833**a**	6,763,051**a**	2.41**a**
LSD	1,380,225	1,236,707	0.28
Level of probability	*	***	***

Mean values with identical letters within the column are not statistically different at $p < 0.05$)

Cassava + maize + bean intercropping system under the present evaluation was 38 % costier in the Mumirwa AEZ, but at the same time generated higher returns (+ 126 %) and V/C ratio (=2.41) in the same agro-ecological zone. With a V/C ratio of 2.42, the cassava + maize + bean intercropping system was more profitable in the conditions of the Mumirwa AEZ rather than the Kirimiro AEZ.

Comparison between bean'sowing time, either at the same time as other crops or with a 3-week delay is illustrated in Table 5c below, which highlights that bean (*Phaseolus vulgaris* L.) planted at the same time as other crops or delayed for three-weeks are associated with almost the same cost. However, 36 % more returns are obtained when all three crops are sown/planted at the same time with a V/C ratio = 2.36 (>2). This translates into more profitability of the tested cassava + maize + bean intercropping system when all three crops are planted at the same time.

Table 5c. Effect of Bean Planting Date on Total Costs (FBu/ha), Returns (FBu/ha) and V/C Ratio

Bean Planting Date	**Costs**	**Returns**	**V/C**
Same Time as other crops	4,173,340**b**	5,623,423**a**	2.36**a**
3-Week Delay	4,324,352**a**	4,131,528**b**	1.92**b**
LSD	152,640	1,236,707	0.28
Level of probability	***	*	**

Mean values with identical letters within the column are not statistically different at $p < 0.05$)

The only significant effects of planting density were observed on costs ($p < 0.001$) and V/C ($p < 0.05$), as indicated in Table 5d below.

Table 5d. Effect of Planting Density on Total Costs (FBu/ha) and V/C Ratio

Planting Density	**Costs**	**V/C**
RS (100 %)	4,907,936**a**	1.88**b**
RS + 20 %	**3,644,268c**	**2.39a**
RS + 40 %	4,194,335**b**	2.14**ab**
LSD	720,124	0.35
Level of probability	***	*

Mean values with identical letters within the column are not statistically different at $p < 0.05$)

Higher costs were registered with recommended plant spacing (RS) for all three crops, followed by RS + 40 % and lastly by RS + 20 %. Consequently, V/C ratios followed the order RS + 20 % (**=2.39**) > RS + 40 % (**= 2.14**) > RS (= **1.88**), indicating that RS + 20 % is more economically profitable, RS + 40 % barely profitable and RS non profitable with reference to FAO standards [21].

An attempt to analyze separately the two AEZ (Kirimiro and Mumirwa) showed the following results. In the Kirimiro AEZ bean (*Phaseolus vulgaris* L.) production was 60 % higher when planted at the same time as other crops than when delayed for three-weeks. Similar tendancies were observed for returns (+ 72 %), V/C (+ 34 %), energy (+ 60 %) and proteins (+ 60 %) yields. On the opposite, bean 3-week delay favored maize (*Zea mays* L.) yield (+ 42 %), energy and proteins yields (+ 42 %). The same

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trends in agronomic, economic as well as nutritional values was also observed in the Mumirwa AEZ with lower bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) productions but higher cassava (*Manihot esculenta* Crantz) yields.

Detailed % distribution of major cost posts is illustrated in Table 6. It can be observed that the two costiest posts and thus limiting factors of profitability are fertilizers application + pesticides application and labor. The two posts account for 60-64 and 65-68 % of the total costs, respectively in the Mumirwa and Kirimiro experimental sites. Therefore, any attempt to maximize the profitability of the intercropping systems should minimize the costs of chemical (fertilizer and pesticides) inputs and labor.

Table 6. Percentage (%) distribution of costs under different cassava-maize-bean intercrops

AEZ/Treatments	Labor	Seeds	Chemical Inputs	Stakes
Mumirwa				
T_1=T_4	39.8	12.6	35.1	12.5
T_2=T_5	54.2	10.8	26.1	8.9
T_3=T_6	47.7	9.6	32.3	10.4
Kirimiro				
T_1=T_4	42.0	9.3	36.8	12.0
T_2=T_5	56.3	8.4	26.9	8.3
T_3=T_6	50.4	6.0	333.7	9.9

Climbing stakes for beans (*Phaseolus vulgaris* L.) represent less than 10 % of the total costs accross experimental sites and cropping systems. As stated in previous publications [13, 14], this cost post could be minimized if one uses maize (*Zea mays* L.) stalks after crop harvest or agroforestry species (*Calliandra calothyrsus* Meisn) installed on live hedgerows for soil erosion control. Another alternative would be to take into account the cassava (*Manihot esculenta* Crantz) and bean (*Phaseolus vulgaris* L.) fresh leaves generally harvested and consumed as vegetable by farmers during crop growth. These could be some of the operations to consider in an attempt to increase the global profitability of the cassava-maize-bean intercropping.

It is very relevant that double and multi-cropping systems are meeting the interest of numerous scientists mainly of the developing world [13,14]. However, due to the combination of the many and diversified factors involved, intercropping systems' studies are not easy because confronted to numerous challenges. Competition constitutes the major factor affecting growth and yield of plant species intercrop. Better yields of intercrops are obtained when interspecific competition is limited as compared to the intra-specific competition [21]. Site-specific factors are related to climate (rainfall, temperature, photoperiodism), soil properties, socio-economic constraints, labor and time constraints. Besides performances of intercropping systems can be managed and achieved through sound field operations. These comprise land preparation, tillage, deases and pest control, morphological and physiological aspects of intercrops, patterns and spatial arrangement, fertilization, seeding ratios, plant densities, dates of planting [23-24].

The present study focused on the last two agriculture practices and is in agreement with some other studies on the intercropping systems. For exemple, in a study conducted by Habte et al., 2016 [25] on maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.) intercropping, it was reported that population density had significant effect on yield of common bean (*Phaseolus vulgaris* L.) and optimum density of components determined. Also, C. Nwokoro (2022) [26] found and reported that increasing plant density of maize (*Zea mays* L.) increased productivity of the cassava-maize cropping system in Nigeria. These investigations even went further and advanced recommandations according to soil fertility status. They advised implementing 12,500 plants/ha of cassava (*Manihot esculenta* Crantz) for 40.000 plants/ha of maize (*Zea mays* L.) on fertile soils and 20,000 plants/ha on nutrient-limited soils, hence highlighting soil fertility and fertilization effects on the performances of intercropping systems. An interesting research topic to consider in the Burundi context in general, and within the UPH research agenda, in particular.

In another study on the influence of cassava population density on the growth and yield performance of cassava-maize intercrop with a relayed cowpea (*Vigna unguiculata* L. Walph), O.T. Ayoola and E.A Makinde (2008) [27] observed that cassava (*Manihot esculenta* Crantz) decreased yield and yield components of intercropped maize (*Zea mays* L.). In the present investigation, we observed similar results as high cassava (*Manihot esculenta* Crantz) yields in the Mumirwa AEZ corresponded to lower bean yields, whereas lower cassava (*Manihot esculenta* Crantz) yields in the Kirimiro AEZ corresponded to higher bean (*Phaseolus vulgaris* L.) yields in the Kirimiro AEZ.

Concerning bean planting date, the present study clearly demonstrated that bean (*Phaseolus vulgaris* L.) planting delay favored maize (*Zea mays* L.) yields, while simultaneous installation of the cassava-maize-bean intercrops increased bean (*Phaseolus*

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vulgaris L.) yields. This might be partially due to the inter-specific crop competition factor but also to the limited growing time of bean (*Phaseolus vulgaris* L.) when planted with a 3-week delay.

4. CONCLUSION AND PERSPECTIVES

The global objective of the present investigation was to evaluate the advantages of the cassava-maize-bean intercropping system, relative to plant densities and bean planting delay under two major Burundi agro-ecological zones (AEZ), Mumirwa and Kirimiro. Specifically, the different intercropping systems were assessed based on their effects on intercrops and total yields, nutrient value (energy, proteins) and economic benefits (gross monetary values, total costs, net returns and value/cost ratio -V/C). Crop varieties used were those recommended by the Burundi Agriculture Research Institute (ISABU) in the particular agro-ecological zones. The twin experiments were conducted in both Kirimiro and Mumirwa agro-ecological zones (AEZ) in a completely randomized bloc design. Six trearments were tested: **T_1**: Recommended spacing (RS) in monocropping systems, **T_2**: RS with reduction of 20 % [RS + (RS*20 %)], **T_3**: RS with reduction of 40 % [RS + (RS*40 %)], **T_4**: RS with bean crop planted three weeks after cassava and maize, **T_5**: RS with bean crop planted three weeks after cassava and maize and with reduction of 20 % [RS + (RS*20 %)] and **T_6**: RS withbean crop planted three weeks after cassava and maize and with reduction of 40 % [RS + (RS*40 %)]. Delaying bean sowing by thre weeks favored maize yields. Planting intercrops at the same time increased bean energy (+ 60 %) more than the 3-week bean planting delay alternative. On the contrary, the latter option favored (+ 37 %) maize energy contribution. Bean sown with a 3-week delay generated 37 % more maize yields, as compared to the simultaneous three crop installation. Table 4c indicates that planting intercrops at the same time increased bean energy (+ 60 %) more than the 3-week bean planting delay alternative. On the contrary, the latter option favored (+ 37 %) maize energy contribution. Highest protein yields are observed in the Kirimiro AEZ for bean ($p < 0.001$) and in the Mumirwa AEZ for cassava ($p < 0.05$). Planting bean at the same time as maize and cassava yielded more proteins (+ 60 %) for bean ($p < 0.001$) and cassava + maize + bean (+ 32 %) ($p < 0.001$). Bean produces more proteins when sown at the same time as cassava and maize crops. Three-week bean delayed planting benefited maize protein contribution. As was the case for maize yield (Table 1c). Maize contribution across AEZ was almost insignificant because of its low yields and practiced selling prices. Bean contributed more in the Kirimiro AEZ, while cassava contributed more in the Mumirwa AEZ. However, 36 % more returns are obtained when all three crops are sown/planted at the same time with a V/C ratio = 2.36 (>2). This translates into more profitability of the tested cassava + maize + bean intercropping system when all three crops are planted at the same time. Concerning bean planting date, the present study clearly demonstrated that bean planting delay favored maize yields, while simultaneous installation of the cassa-maize-bean intercrops increased bean yields. Cassava represents 82 % of the total yields, while bean and maize represent only 11 and 7 %, respectively. In the Kirimiro AEZ, comparative figures are only 54 % for cassava, 33 % for bean and 13 % for maize. Planting bean at the same time as the other two crops, (cassava and maize) yielded significantly higher (+ 60 %) than bean sown 3-week after cassava and maize. On the opposite, bean sown with a 3-week delay generated 37 % more maize yields, as compared to the simultaneous three crop installation. Cassava (*Manihot esculenta* Crantz) represents 64 % of the total energy yields in the Mumirwa AEZ. In the same agro-ecological zone, bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) represent 20 and 16 %, respectively. In the Kirimiro AEZ, similar figures are 34 % for cassava (*Manihot esculenta* Crantz), 46 % for bean (*Phaseolus vulgaris* L.) and 20 % for maize (*Zea mays* L.). Bean (*Phaseolus vulgaris* L.) contributes 77 % of the total proteins when all three crops are installed at the same time, whereas maize (*Zea mays* L.) brings in 10 % and cassava (*Manihot esculenta* Crantz) 13 % of proteins, respectively. In case the bean (*Phaseolus vulgaris* L.) crop is sown 3-week after cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) crops, bean (*Phaseolus vulgaris* L.) contribution is reduced to 64 %, when maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz) contribute for 19 % and 17 % of proteins, respectively. Bean (*Phaseolus vulgaris* L.) produces more proteins when sown at the same time as cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) crops. On the contrary, maize (*Zea mays* L.) produced more proteins when bean (*Phaseolus vulgaris* L.) is sown 3-week later. Bean generated 23 % more money in the Kirimiro AEZ while cassava yielded three-times more money in the Mumirwa AEZ. Overall, money generated through the cassava + maize + bean intercropping was two times higher in the Mumirwa than in the Kirimiro AEZ. In the Kirimiro AEZ, bean (*Phaseolus vulgaris* L.) contributed for 60 % of the total monetary values and only 27 % in the Mumirwa AEZ. A similar reflexion applied to cassava (*Manihot esculenta* Crantz) indicates that the former crop contributed to the crop yield global monetary value for 67 % in the Mumirwa AEZ and 30 % in the Kirimiro AEZ. Maize (*Zea mays* L.) monetary contribution to the global monetary values was 10 % in the Kirimiro AEZ and 6 % in the Mumirwa AEZ. Maize (*Zea mays* L.) contribution across AEZ was almost insignificant because of its low yields and practiced selling prices. Bean (*Phaseolus vulgaris* L.) contributed more in the Kirimiro AEZ, while cassava (*Manihot esculenta* Crantz) contributed more in the Mumirwa AEZ. However, 36 % more returns are obtained when all three crops are sown/planted at the same time with a V/C ratio = 2.36 (>2). This leads into more profitability of the tested cassava + maize + bean intercropping system when all three crops are planted at the same time. With a V/C ratio of 2.42, the cassava + maize + bean intercropping system was more profitable in the conditions of the Mumirwa AEZ rather than the Kirimiro AEZ. In the Kirimiro AEZ bean (*Phaseolus vulgaris* L.) production was 60 % higher when planted at the same time as other crops than when delayed for three-weeks. Similar tendancies were observed for returns (+ 72 %), V/C (+ 34 %), energy (+ 60 %) and

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proteins (+ 60 %) yields. On the opposite, bean 3-week delay favored maize (*Zea mays* L.) yield (+ 42 %), energy and proteins yields (+ 42 %). The same trends in agronomic, economic as well as nutritional values was also observed in the Mumirwa AEZ with lower bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) productions but higher cassava (*Manihot esculenta* Crantz) yields. Concerning bean planting date, the present study clearly demonstrated that bean (*Phaseolus vulgaris* L.) planting delay favored maize (*Zea mays* L.) yields, while simultaneous installation of the cassa-maize-bean intercops increased bean (*Phaseolus vulgaris* L.) yields. Conclusively, more returns (+ 36 %) were obtained when all three crops were sown/planted at the same time with a V/C ratio = 2.36, while effect of crop density/spacing indicated that recommended crop spacing increased by 20 % (RS + 20 %) was more economically profitable (V/C=2.39). Such treatment combination corresponds to T_2, which is the treatment to currently promote by extensionnists and valorized by farmers. Meanwhile, a challenge remains before agronomists involved in intercropping systems evaluation: what should be the optimal fertilization practices suitable to such systems? This topic should undoubtedly be the next research step to be undertaken by the UPH/UB/ADISCO scientific consortium in their better understanding of cassava-maize-bean intercropping systems in Burundi.

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