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AGROECOLOGICAL DISTRIBUTION OF BANANA SYSTEMS IN THE GREAT LAKES REGION

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ABSTRACT

Banana (*Musa* spp.) is important in the Great Lakes region of Africa as a staple food crop and source of income for the rural poor who also use it for various purposes; medicinal, cultural as well as industrial. The crop is grown across diverse agroecological conditions ranging from lowlands at sea level to highlands above 1500 m.a.s.l. Equally diverse are the socio-economic conditions associated with the crop across the region. The region is dominated both in production and acreage by the East African Highland bananas. Plantain and Cavendish production on the other hand dominate at the lower altitudes where the acreage under banana cultivation is steadily increasing. The agroecological diversity and the effects of socio-economic factors may have far-reaching implications to strategic planning for increased productivity of bananas especially considering possible effects on food security, pest/disease control, cultivar diversity and market/income. Using secondary information including existing databases on climate, land use/cover and edaphic factors, principal banana production areas have been mapped and an attempt made to overlay these with selected bio-physical and socio-economic factors in order to elucidate basic agroecological characteristics of these areas. The outcome clearly indicates that there exists potential for attaining food security and stable income, given the better climatic conditions prevailing, existing germplasm banks and near favourable accessibility. Opportunities and constraints based on climate, edaphic, human population densities and accessibility are recommended for further research and developments.

Key Words: Food security, geographic information systems (GIS), *Musa* spp., socio-economic factors

RÉSUMÉ

La banane (*Musa* spp.) est importante dans la région des grands lacs comme nourriture de base et source des revenues pour les populations pauvres qui l'utilisent également pour d'autres buts, médical, culturel, et aussi bien qu'industriel. La plante est cultivée à travers diverses conditions agro écologiques des plaines aux hautes terres à 1500 m au dessus du niveau de la mer. Egalement diverses sont les conditions socio-économiques associées avec la plante à la région. La région est dominée en production et superficie par les bananes des hautes terres de l'Afrique de l'Est. La production de plantains et de Cavendish d'autre part est dominante dans les basses altitudes ou la superficie sous la banane est constamment croissante. La diversité agro écologique et les effets liés aux facteurs socio-économiques pourraient avoir entamé les stratégies de planification pour améliorer la productivité de la banane avec des effets sur la sécurité alimentaire, le contrôle de pestes/maladies, la diversité des variétés et le marché/revenu. L'utilisation des données secondaires, la base des données climatiques existante, l'utilisation des terres/ couverture végétale et les facteurs locaux, les zones de productions de la banana ont été identifiées et ont été super imposées sur les facteurs biophysiques et socio-économiques afin d'élucider les caractéristiques agro écologiques de base de ces zones. Le résultat indique clairement qu'il existe un potentiel pour atteindre la sécurité alimentaire et un revenu stable, étant donné l'existence des bonnes conditions climatiques, l'existence d'une banque de protoplasmes des germes et une bonne accessibilité. Les opportunités et les contraintes basées sur le climat, les conditions locales, la densité de la population humaine et l'accessibilité sont recommandées pour des recherches plus détaillées.

Mots Clés: Sécurité alimentaire, système d'information géographique, *Musa* spp., facteurs socio-économiques

INTRODUCTION

The banana system, like all the agricultural systems in the Great Lakes region, is diverse - a product of interaction of the various factors governing land use (Karamura *et al.*, 1996). Similarly, banana farmers use a complex of resources that are located in a geographic space, farms and their surroundings to satisfy their various production objectives. It is this spatial area, typically consisting of various resource combinations, and its associated linkages, that forms the logical focus for research and development efforts targeting the wise use of such resources for food security and income generation. Spatial variation is generally considered a complicating factor in agricultural research, while location specificity is often viewed as a primary factor leading to the downfall of farming systems research (Carter *et al.*, 1994). This perspective stems directly from the desire for agricultural research institutions to develop and transfer technologies that will have a wide geographical and hence socio-economic impact. Farmer-specific socio-economic, institutional and policy factors interact with the physical environment to influence the process of technology transfer.

In the highland eco-systems, where bulk of the bananas in the Great Lakes region is produced, are found a myriad of potential niches long associated with the development of diverse human agro-ecosystems - each niche providing specific opportunities and constraints. A clear understanding of the differences in the different settings is vital for the design of appropriate research and transfer of relevant technologies. An analysis of these spatial relationships becomes essential for the improvement of our understanding of existing opportunities and constraints with which comes the possibility of making generalisations. The systematic identification of the opportunities and constraints is the task of characterisation. Characterisation schemes are increasingly becoming standard tools for targeting agricultural research and setting research priorities mostly because they offer relevant and available information about target areas, environments, or ecologies. 'Determinants' of ecosystem character, it is argued, are: climate, edaphic factors and disturbances (anthropogenic and natural) being first, second and third order, respectively (Corbett, 1996). This hierarchy to determine opportunities and constraints on ecosystem structure, the so-called 'ecological hierarchy theory', provides a useful model to characterise agricultural environments.

With agricultural environments characterised, useful information will be available to research and development stakeholders for effective planning and targeting of research and development activities.

However, meaningful characterisation of agro-ecosystems requires availability of accurate spatial and temporal databases. The need for exclusive synthesis also requires that the various data sets can be integrated. It is now possible, through Geographic Information Systems (GIS) techniques, to integrate the many scales of data developed in and for agricultural research for this purpose - hence loosening former restriction to data integration. Important variables have to be identified and mapped, often in electronic form to allow for GIS-based analyses.

The objective of this work was to apply advances in data integration capabilities in an attempt to describe the biophysical and socio-economic characteristics of the principal banana production areas (PBPAs) of the Great Lakes region with a view to document underlying opportunities and constraints. The results should provide supplementary information for assessing the potential or effects of existing or future banana research and development efforts thereby stimulating thinking towards more explicit integration of this information into the research and development planning process.

MATERIALS AND METHODS

Banana production data from national statistics were used in conjunction with the administrative units, land use/cover and gazetted areas to estimate the proportion of land area in banana. The esimated banana production intensity maps were overlaid with the natural/farming systems regions or agro-ecological divisions and subjected to expert opinion to isolate and define the principal banana production areas (PBPAs) for the respective countries (Fig.1. and Table 1).

The PBPAs were overlain with terrain (altitude), annual rainfall, length of growing season, soils, human population density and access to roads. These provided information on proportions/ locations of the PBPA in the respective factor class or unit considered of relevance to banana production and management.

The natural farming systems or agroecological regions are adapted from Wortmann *et al.* (1998), Nzisabira (1989) and Wortmann and Eledu (1999a) for Burundi, Kenya and Tanzania, Rwanda and Uganda, respectively. Grid terrain and land use/cover data originating from the United States Geological Surveys (USGS) were used for all countries except Kenya and Uganda, which had national digital data. Data on annual rainfall was from the Africa climate database (Hutchinson, 1995). Length of growing season has been estimated as number of wet months (Africa Climate database) and length of best period where P/PE > 0.5 (Corbett *et al.*, 1995). Digital soil data for the region is somewhat limited. Soil water holding capacity is that derived by the World Soils Resources Group of the United States Department of Agriculture (USDA) from the attribute information of the FAO soil map (FAO, 1996) from which also major/dominant soils constituting the PBPA is documented. Estimates of K and pH are from the soil map of Uganda (Wortmann and Eledu, 1999a). For uniformity and digital data availability, human population density data is taken from the Africa population density grid after Deichman, 1994. The road network and gazetted areas used originate from the Africa Data Sampler - a geo-referenced database for African countries and access is the linear distance to the nearest minimum of a primary road without considering the quality of the road. Basic statistical and GIS tools were used (Word Resources Institute, 1995).

RESULTS AND DISCUSSIONS

True to the name East African highland bananas (EAHB), over 75% of PBPA of the Great Lakes region which grow almost exclusively EAHB are located in the highlands (between 1000 and 2000 masl) were temperatures are optimum for banana production. Some 3% however occur in the cooler highland areas mostly in Kenya and Burundi but also important in the other countries. About 30,000 Km^2 of the PBPA - mostly coastal Kenya and Tanzania - is located between sea level and 500

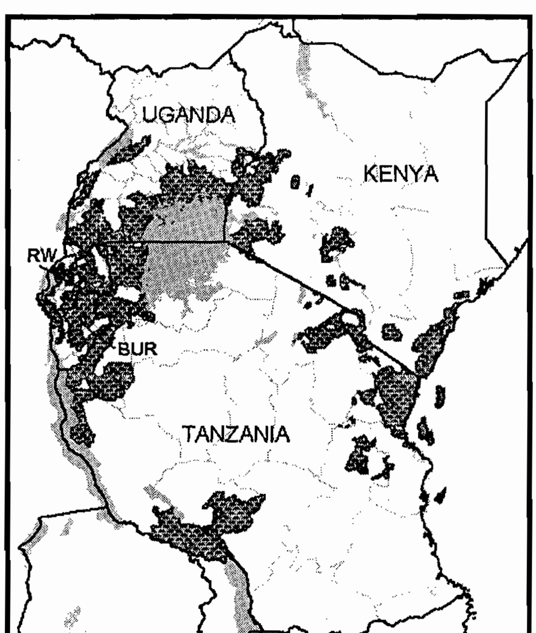

Figure 1. Principal banana production areas in the Great Lakes region.

TABLE 1. The Principal Banana Production Areas (PBPAs)

Country	PBPAs
Burundi	Zaire-Nile Crest: Mumirwa and Mugamba natural regions comprising mainly Eastern and parts Sounthern fringes of Bujumbura
	Imbo Plains: Imbo natural region comprising parts of Chibitoke/ Bumbaza areas outside the park
	Central Plateau: Kayanza/Muramvya areas outside the park, Ngozi, Kirundo and northern Muyinga, Gitega and Karuzi hills
	Central plateau - Bugeresa
	Moso Plateau: Kayongoro in Makamba; East Giharo/Musongati/Rutana areas in Rutana; Nyabitsinda/Kinyinya/Gisira in Ruyiga and Cendajuru/N. Kigamba areas in Cankuzo
Kenya	Coast region: comprising predominantly the Coastal Lowlands- Kwale/Malindi/Kilifi areas and the Taita hills
	Central highlands: Thika/Kiambu/Muranga/Maragwa areas
	Rift Valley: W. Pokot/Transzoia, S. Baringo, Bomet and Kajiado areas
	Western: around Lake region comprising South Nyanza and Western province
Rwanda	Lake Kivu Basin (also called L. Kivu shore: comprising Cyangugu outside Nyungwe forest, Gishenyi West of Gishwati forest and Kibuye
	Buberuka foothills: Gishenyi East of Gishwati forest on what is sometimes called Zaire-Nile Crest, Kigali rural North of Kigali ville and Southern ditricts of Byumba bordering Kigali rural
	Central Plateau: Central/North Gitarama and Butare
	Eastern Lowlands - Kigali/Byumba: Kigali rural South of and including the Kigali ville, East and Southern Byumba, recent habitation areas in Akagera park which form part of Umutara and Ntongwe/Mugina in E. Gitarama
	Eastern lowlands - Kibungo
Tanzania	Kagera region: comprising mostly the Bukoban/Karagwe-Ankolean systems where the banana distrcits of Bukoba and Karagwe are found
	Western - Kigoma
	Northern and Northeastern Highlands: the Kilimanjaro footslopes in Kilimanjaro region and Monduli/Arumeru in Arusha region with some pockets at the border district of Tarime in Mara region
	Coastal Lowlands: Pwani/Tanga lowlands including the Islands of Pemba and Zanzibar Southern Highlands: Mbeya area
	Usambara/Uluguru highlands: comprising Lushoto in Tanga andMororgoro in Mororgoro
Uganda	Mt. Elgon: Sebei-Kapchorwa farm/highlands
	L. Victoria crescent: Ssese Is., Sango plains and the southern parts of the L. Kyoga basin
	S. Western Grass-Farmlands: Mbarara, Ntungamo areas
	S. Western Highlands: E. Kabale and Southern parts of Kanungu
	Western Mid-altitude farmlands: Hoima-Masindi areas
	Southwestern farmlands and Rwenzori footslopes: mid-altitude to highlands areas of Bushenyi, Rukungiri and parts of Kanungu/Ntungamo/Mbarara

masl and is where the AAA Cavendish is predominantly grown.

Water/moisture requirement. Banana is a year-round crop, which requires plenty of water that is well distributed throughout the year (Table 2a and 2b). In the banana systems in the region, all the development stages of the crop can be found in a given plantation at any one time of the year (main crop and ratoon crop) and the growers depend almost entirely on natural rainfall. At least 1000 mm of rainfall in a year with no more than 2-3 dry months has been suggested; where a dry month is a month with rainfall under 60 mm (Jagtap, 1993). Considering only total annual rainfall and assuming at least 1000 mm of rainfall annually, about a half of the PBPA in the region would require supplementary water; higher in areas where the AAA Cavendish is predominant as one moves further inland (Table 3a). This implies that the situation is best in the PBPAs of Burundi and worse in the PBPAs of Tanzania. On the other hand, based on wetness (or dryness) of the months, 85% or 68% of the PBPAs lie in areas where there are more than 2 or 3 dry months, respectively, especially in the PBPAs of Tanzania, Burundi and Rwanda (Table 3b). This suggests that rainfall is not well distributed throughout the year more especially in the PBPAs of Burundi and Tanzania. Rainfall distribution seems better in the case of PBPAs of Rwanda.

Available water is a function of the total amount of rainfall and its distribution. Moreover, rainfall will always vary spatially, seasonally and annually. Whatever the rainfall regime in an area, the amount of water available to the crop will depend also on how much can be held by the soil. Almost a third of the PBPA occurring within the wet regime is again found in areas with very low to low soil water holding capacity (Table 3c).

The capacity of the soil to hold water for later use by the crop will also be determined by how much evapotranspiration requirements of the area would have been satisfied. The period for which rainfall is enough to satisfy potential evapotranspiration ("growing season") - the most suitable time of the year for crop growth has been defined in many ways. Corbett (1996) suggest that the ratio P/PE > 0.5 (ratio of precipitation to potential evapotranspiration) is a reasonable indicator of conditions, which are approaching climatological suitability for crop production. Whereas banana is a all-year crop, with all stages of the crop cycle occurring at any one time of the year, about 75% of the PBPA lies in areas where length of "Best" period of P/PE > 0.5 is under nine months (Table 3d).

It is apparent that there is a problem of rainfall distribution in the PBPAs, requiring strict soil/soil-water management strategies in bulk of the banana system in the region.

As the second order determinant of eco-

TABLE 2a. Information on banana (National Banana Program, NARO, 1999 - unpubl.)

Type of planting material	Time to flowering	Flowering to harvesting	Planting to harvesting
Maiden sucker	6 - 12 months	3 - 6 months	9 - 18 months
Sword sucker/Tissue culture plantlet	9 - 12 months	3 - 6 months	12 - 18 months

TABLE 2b. Average water and mineral immobilisation by one Grande Naine banana plant for a crop yield level around 60-65 t ha^{-1} (harvesting stage, roots excluded) (Lahav, 1995)

	Whole plant	Fruit
Fresh weight (kg)	175	63
Water mass (kg)	137	31
Mineral nutrients (g)		
N	175	63
K	647	185
P	18	7.5

TABLE 3a. PBPAs in various annual rainfall regimes

	S. Arid (400-800mm)	M. Wet (800-1000)	Wet >=1000mm)
PBPA. Burundi	-	13%	87%
PBPA. Tanzania	17%	39%	44%
PBPA.Rwanda	-	44%	56%
PBPA.Kenya	18%	22%	60%
PBPA.Uganda	4%	19%	77%
Region	12%	30%	58%

character, soil is already featured in its role in soil water conservation. However, even in well-watered areas, crop production risk will more closely be related to soil nutrient competition, which is also dependent on the soil nutrient status and availability (Corbett, 1996).

Soil fertility conditions. The PBPA occur in a wide variety of soils spreading over 25 different soil units and climatic zones further complicating the spatial complexity of the PBPAs! The important soils - soils on which at least 80% PBPAs occur - are detailed in Tables 4a and 4b and their general description provided in Table 5. About a half of the PBPAs specifically occur on Orthic Ferralsols (Fo) and Ferric Luvisols (Lf). In the PBPAs of Kenya, Rwanda and Burundi Humic Nitisols (Nh) are also important and featuring specifically in Tanzania is Chromic Cambisols (Bc). The major soils for food production in Africa have been described by Sant'Anna (FAO, 1993). The capacity of the soil to supply nutrients is influenced by moisture conditions and soil temperature and management practices.

Ferralsols, Nitosols, Acrisols and Arenosols – in the humid zone - are very extensively developed and for the most part deeply weathered and gravelly, mostly acid to very acid in reaction but with a considerable amount of organic matter built up under natural conditions. Inherent fertility status is quite high in uncultivated soils, initially allowing extensive cultivation of a wide range of cash and food crops. But after two to five cropping seasons which is the case in the PBPAs, however, the nutrient levels are so reduced that farmers would be obliged to abandon the cropped field for a newly cleared one, now limited by population pressure. Other constraints which limit the ability of these deeply-weathered soils to produce in this region are low cation-exchange capacity; weak retention of bases applied as fertilisers; fixation of phosphates; deficiencies of calcium, sulphur and trace elements; leaching during the rainy season; with moderate to high risk of erosion.

In the humid to sub-humid areas (e.g., in S. Western Kenya and Northern border tip of Burundi), these soils are generally well drained, light textured sometimes overlying an iron pan

TABLE 3b. PBPAs versus number of "wet" months

	≥ 10 wet months	≥ 9 wet months
PBPA. Burundi	0%	17%
PBPA. Tanzania	1%	9%
PBPA.Rwanda	1%	66%
PBPA.Kenya	32%	45%
PBPA.Uganda	44%	74%
Region	15%	32%

TABLE 3c. PBPAs rainfall regimes versus soil water-holding capacity (regional)

	Very low (<50 mm)	Low (50-100 mm)	Medium (100 - 150 mm)	High (150 - 200 mm)	Very high (>200 mm)
Arid	-	-	-	-	-
Semi arid	1%	4%	3%	4%	0%
Moderately wet	2%	10%	12%	5%	0%
Wet	3%	23%	11%	17%	2%

TABLE 3d. PBPAs in Length of "Best" period (months)

	PBPA.BUR	PBPA.TZ	PBPA.RW	PBPA.KEN	PBPA.UG	Region
7 under	33%	85%	-	61%	40%	60%
8	52%	8%	38%	6%	1%	15%
9	15%	5%	59%	8%	24%	13%
10 over	-	2%	3%	25%	35%	11%

TABLE 4a. PBPA in FAO soil grouping

	Region	PBPA.BUR	PBPA.TZ	PBPA.RW	PBPA.KEN	PBPA.UG
Ferralsols	27%	71%	6%	43%	26%	60%
Nitosols	18%	20%	13%	45%	24%	11%
Luvisols	13%		23%		16%	
Acrisols	8%		9%			
Cambisols	7%		12%			14%
Arenosols	5%		21%		16%	
Gleysols	5%		5%			
Planosols	-		7			
Regosols	-		6			
Other	17%	3%	18%	12%	19%	15%
No. of soil units	6	3	5	5	8	5

TABLE 4b. PBPA in USDA soil order

		Region
Oxisols	Udox	23%
Ultisols	Humults, Ustults, Udults	22%
Alfisols	Ustalfs	19%
Inceptisols	Tropepts, Aquepts	12%
Entisols	Psamments	5%
Other		18%

and are of a lower inherent fertility status. Increased and sustained production may require fertiliser application and use of strict soil and water conservation measures. Predominant soil-related constraints in this area are moisture stress and sensitivity to erosion, low CEC, high base saturation, low K, micronutrient deficiencies, low aggregate stability and surface sealing resulting in increased runoff; root-zone limitation due to surface layers of plinthite, ferruginous concretion

TABLE 5. Arrangements of soils according to geography and soil development stages

Soil	Development	Characteristics
Ferralsols	Deep, intensively weathered soil (ferralic B horizon)	Sub-surface horizon mainly of kaolinitic clay and residual concentration of quartz and hydrated oxides of iron and aluminium; low capacity to retain ions
Nitisols Luvisols Acrisols	Soils with marked accumulation of clay (argic B horizon)	Very thick sub-surface horizon with nitic properties (shiny ped faces on strong blocky structural peds) BSP $\geq$ 50; CEC $\geq$ 24 me/100g clay BSP < 50; CEC < 24 me/100g clay
Cambisols	Slightly developed soils	Parent material alteration in wet, moist or dry conditions; weak soil structure; neoformation of clays and iron oxides; lack appreciable alluviation; BSP < 50
Arenosols	Soils with strong influence of parent material	In unconsolidated sandy deposits of at least 10 cm thickness, other than alluvial or andic; weakly developed sub-surface horizon or albic E horizon.
Gleysols	Soils with hydromorphic characterisitc	In unconsolidated materials, showing strong influence of ground water at shallow depth; greyish or bluish colours with or without reddish, brownish or black mottles

and/or iron pan. Mulching and ridging may be effective in controlling soil erosion.

Cambisols are, however, more recently formed and are thus, inherently more fertile. In most cases, however, hilly relief and stoniness limit their development.

Gleysols, one of the major lowland soil are generally deep, non-gravelly, and of medium to heavy texture but are subject to water-logging and flooding during the rainy season, so effective drainage control measures are needed to increase and sustain crop production. Gleysols occurring in the lowland area of the humid to sub-humid savannah are mostly non-gravelly with a reasonably moderate to high inherent fertility status, making them more productive than their upland Gleysols. But where lowland clayey soils are extensive, the main constraints are tillage difficulties, caused by stickiness when wet and hardness when dry, slow permeability, slow internal and external drainage, seasonal waterlogging, flood risk and in certain cases, salinity and alkalinity. Luvisols are included in this group.

To further illustrate some of the above concerns, about one third of the PBPA in Uganda occupy soil in which at least 75% is low in Potasium (K) particularly the L. Victoria Crescent and the Masindi/Hoima areas where some of the same area also exhibit acidic tendencies. Potasium is an important soil nutrient for banana production. Low K and acidity levels are set at exchangeable K < 0.3 meq/100g and pH < 5.5 estimated from actual K and pH measurements, respectively (Wortmann and Eledu, 1999b). Deliberate soil fertility management interventions are clearly manifest in the PBPAs in their variety and extent.

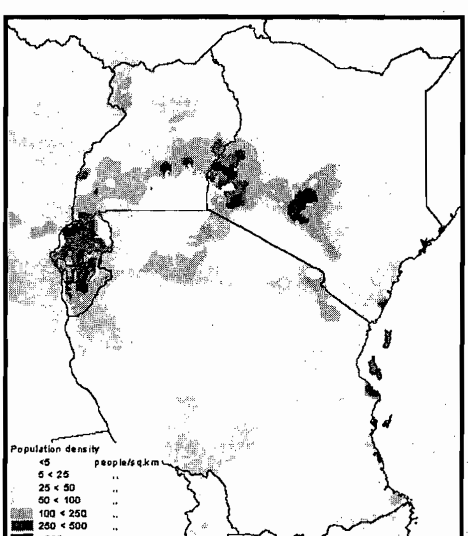

Figure 2. Human population density.

Human factor. Looking at the PBPAs map and the human population density (Fig. 1 compared to Fig. 2), it is clear that banana as a crop and food is closely associated with human population density areas. Population density levels in the PBPAs are mostly over 50 persons/Km^2 exceeding 250 persons/Km^2 in about 90% of the PBPAs of Rwanda. 96, 93, 88, 60, 40 and 60 percent of the PBPAs of Rwanda, Burundi, Uganda, Kenya, Tanzania and the region respectively is home to at least 50 persons/Km^2.

The banana system in this region is associated with intensively cultivated land use systems. Average percent agricultural land area within a 5 x 5 km^2 grid stands at about 50%. Over a third of the production systems occupy areas where more than three-quarters of land area is cultivated. Highest land use intensities occur in PBPAs of Uganda, Burundi, Rwanda and Tanzania, especially in the Imbo plains (Burundi); S. Western highlands/Rwenzori footslopes and Mt. Elgon farm-highlands (Uganda); Coastal lowlands

(Tanzania); and L. Victoria/Kyaga crescent/basin (Uganda). Apart from factor endowment and exposure to agroclimatological risks, differences in the household access to financial and commodity markets significantly influence its cropping shares and farm income.

Accessibility and infrastructure. For new technologies to be adopted and for subsistence oriented small holder agriculture to be transformed, access to agricultural markets and related improvements in rural infrastructure and marketing institutions are essential (Zeller *et al.*, 1997, unpublished report). Whatever the technology dissemination methods, the products, the marketing system, etc, road network is key. It is estimated that within 5 km off the roads, farmers can deliver their banana products to markets and/or middlemen. Middlemen have also been known to span at most 5 km off roads on average through agents. A construction of a linear distance from the nearest minimum of a primary road without quality and terrain consideration revealed that over two thirds of the PBPAs lie within 5 km of the nearest primary road (Table 6). Opportunity for market/marketing development in as far as access to roads is concerned is probably favourable albeit with varying degrees within countries.

CONCLUSION

With detailed and accurate digital data on climate factors, soils and socio-economic factors, GIS tools can be used to provide a better insight into opportunities and constraints that might hitherto not be apparent in the design of research and development activities for production systems in general especially their spatial significance or extent. In commodity research, the ecosystem and socio-economy of the target areas is very important if the expectations of the planned interventions are to be realised.

Possible arrays of unique resource combinations are highlighted. There exists spatial complexity of the soil base, which in the absence of "nutrient mining" by the banana system still required deliberate nutrient management. Some special environments seem to exist; requiring specialised attention (e.g., some very cool highland niches) and the significance of population pressure is eminent in the PBPAs. All these bear heavily on productivity of the system and the success of pest and disease management options. Areas with excellent resource combinations can be mapped out to serve as key areas for testing response to technologies.

A system-wide approach, which incorporates the salient issues like the ones highlighted here, is reaffirmed and a detailed synthesis of these factors in the definition of target domains in the banana production systems is justified.

TABLE 6. PBPA within road access classes

	0-5 km	5 -10 km	>10 km
PBPA - Burundi	72.3%	22.1%	5.6%
PBPA - Kenya	78.1%	16.2%	5.7%
PBPA -Rwanda	65.0%	23.0%	12.0%
PBPA -Tanzania	57.4%	22.6%	20.0%
PBPA -Uganda	61.0%	19.5%	19.5%
Region	63.0%	20.8%	16.2%

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