Experience with GPS Equipment in Measuring Crop areas: The Case of Uganda

E.S.K. Muwanga-Zake[1] and J.B. Magezi-Apuuli[2]

Summary

The paper discusses results from agricultural statistics surveys in Uganda which indicate that there is potential to use relatively cheap Global Positioning System (GPS) equipment for measuring area and for geo-referencing of holdings in the context of agricultural statistics. However, this experience shows that there is need for careful setting of the equipment and thorough training of field staff before the GPS tool can be efficiently used. More studies are also recommended concerning the variability and consistency of the equipment, especially for very small plots and where tree cover and/or hilly areas introduce "shadow" and projection problems.

Key Words:

Agricultural Statistics; Census of Agriculture; Uganda Pilot Census of Agriculture (PCA). 2003; Uganda Permanent Agricultural Statistics System (PASS); Area Estimation Methods

1. Introduction

Reliable estimation of annual production of food crops and other agricultural commodities are very important, especially for a developing country such as Uganda which is making serious efforts to tackle the problem of feeding her population, diversifying her export crops and, thus, raising the living standards of her people. Unfortunately, there have been major methodological problems in the estimation of crop production in developing countries, particularly in Africa.

A number of methods of estimating crop production exist including the following: Utilisation Table or Food Balance sheet; Direct Weighing; Farmers' Estimates; Continuous Weighing; Measurements from Researchers; and a Product of Area and Yield. Each of these methods has strengths and weaknesses, particularly in Africa.

One of the most important factors for production used in growing crops, raising livestock or any other farming activity, is land. The pattern of land-use usually varies by seasons or by different regions of the country. Thus, apart from being used in the estimation of agricultural production, accurate data on area used for agricultural purposes is an important aspect of agricultural planning.

Total land operated by the holder (i.e. the agricultural holding) is a crucial variable for the analysis of agricultural data. The area of a holding may vary from time to time. A holder may sell or leave part of his/her holding or he/she may buy or rent from others.

1: Director, Trade and External Debt Department, Bank of Uganda, 37/43 Kampala Road, P.O. Box 7120, Kampala, Uganda. E-mail address: muwangazake@hotmail.com

2: Senior Statiscian, Uganda Bureau of Statistics (UBOS) , P.O.Box 7186, Kampala, Uganda. E-mail adress:magezi.apuuli@ubos.org

At any time the holder has the option to fully or partially utilize the holding. Thus the proportion of the holding under crop also varies from season to season or from year to year. Crop production can be estimated as a product of the Yield and Area. The product can easily be computed in the case crops are grown in pure stand. With mixed cropping, data is collected on the proportions of crop cover, which are then used to apportion the area to the various crops in the mixture to a pure crop equivalent.

Area measurement for use in traditional agricultural statistics has a twofold objective:

- To determine the structural changes of the agricultural holdings i.e. changes in total area size of the holding, size of the different land use categories and also to follow possible fragmentation or aggregation of farmland.
- To enable for determination of the actual and potential agricultural production by calculation of total crop production as a function of yield and area

Geo referencing of agricultural holdings in the context of agricultural statistics become relevant as Geographical Information Systems and Tools (GIS/GIT) is widely introduced in research institutions and civil administration planning units. Exact positioning of holding center and even of parcels and crop-plots can be combined with other geo referenced thematic information and digital base maps for spatial analyses and planning.

2. Experimentation in Area Measurement Using the Geographical Positioning System (GPS) Equipment in Uganda

2.1 Background

In Uganda , like many other countries, there is no complete cadastral map or land register that includes information about holding areas. Experience from previous surveys and censuses also reveals that most of the holders in rural Uganda are not able to accurately determine the size of their land in useable quantitative units. As a consequence, all information about size of land has to be collected by measuring.

Experience from area measurement during the Agricultural Censuses in Uganda in 1963/65 and 1990/91, indicates that the measuring of areas by measuring tape (or wheel) combined with compass use and traversing the perimeter of the selected area is a fairly accurate but very time consuming method. The accuracy of this method however depends on the enumerators capacity to read the compass and correctly apply the tape measurements and also to which extent approximation to the actual shape of the parcel or plot has to be done – the so called "give and take approach". Also the cost for instruments like high quality compass and measuring tapes are considerable (Ministry of Agriculture, 1993).

On this background it was decided to look for alternative methods for area measurements. In this regard, a number of experiments have been carried out in the country using Geographical Positioning System (GPS) Equipment. These include the pre test for the Uganda Census of Agriculture and Livestock conducted in Masaka district in June/July 2002; the Pilot Cen-

sus of Agriculture (PCA), 2003; and the pilot Permanent Agricultural Statistics System (PASS) (Uganda Bureau of Statistics (UBOS) 2002, 2003a, 2003b & 2004a)

The GPS equipment is in principle a high precision digital watch combined with a signal receiver. It finds longitudes and latitudes on the earth's surface. The geographical position is found by continuously measuring the time a signal takes from satellites in the sky to the GPS tool on the earth surface. An obvious advantage that the GPS tool has compared to the traversing with tape and compass is that the perimeter of the area can be followed fairly quickly, accurately and completely, irrespective of its shape.

2.2 Pre-test in Masaka District

Preliminary experimentation was carried out using two hand held GPS equipment of the type Magellan Meridian (www.magellan.com) for area calculation of crop-plots and parcels as well as for geo-referencing of the holding during the pretest.

The findings of the pretest was that, compared to accurate but time consuming traversing of the same areas using compass and measuring tape, the average of the GPS equipment measurements seemed to be of promising accuracy. However the variation in the repeated measurements caused some concern at this stage. GPS equipment based calculation of areas was during the pretest done both by reading results from the device display directly and in addition by downloading the track-log polygons to a GIS software for storage, mapping and area calculations on a lap-top.

The registration of holding point co-ordinates caused no serious problems during the pre-test fieldwork.

2.3 Further experimentation and fine tuning of GPS tool setup

In October/November 2003, more studies of the accuracy and variation of the results were carried out using GPS tools already available in Uganda Bureau of Statistics (UBOS). These had been procured and used in the identification of coordinates for all establishments in the Uganda Business Register.

The tools available were of the type Garmin 12 or Garmin 12XL. Most of these tools already contained the necessary software to calculate areas. Information about upgrading for area calculation software can be found on the Garmin home pages (www.garmin.com).

In cooperation with experts from the National Biomass Study Project and the Principal Cartographer within the UBOS, the instruments setup were optimized for such registrations i.e. the interval for registration recoded to the track-log was minimized and a suitable projection and co-ordinate system was agreed. The latter was also to ensure comparability with already existing digital thematic maps relevant for agriculture presentations and GIS analyses.

During this preparatory experimentation the possibility for downloading vector data for each parcel and plot perimeter was discussed and tested (necessary PC software can be downloaded). For practical reasons this approach was not further followed up. Recording of parcel and plots polygons as vector data would require advanced and expensive systems for transferring large amounts of geographical data from the fieldwork into UBOS storing and processing facilities. In addition, the accuracy of the shape of the polygons registered with a handheld GPS equipment without any adjustment facilities, would

not fulfill technical requirements for use as cadastral maps. Finally, cadastral mapping was also regarded as being outside the scope of a census of agriculture.

During the October/November 2003 studies, it was concluded that the GPS equipment measurements were not statistically significant from those measured by tape and compass at the 5% level of significance.

As a result of the pretest and the following experimentation and fine-tuning, it was decided to expand the experimentation with the GPS tool during the Pilot Census of Agriculture (PCA). The approach agreed for the PCA was to traverse the perimeter of the selected areas with the GPS tool, conduct readings of results of position and areas directly from the GPS equipment display and finally recording the data into traditional statistical questionnaires.

2.4 Testing of GPS equipment during the Pilot Census of Agriculture, 2003

It was decided to compare the various methods for area measurement during the Pilot Census of Agriculture (PCA).

The experimental design of the PCA provided for four approaches to area estimation for three groups of holdings within each Enumeration Area (EA). Each EA had a total of 15 holdings selected, so each of the three randomly selected groups had five (5) holdings. The experimental design for area measurements was as follows:

(i) Holders'/respondents' eye estimates of parcel and crop plot area was recorded on the 5 selected holdings in Group I.
(ii) Enumerators' eye estimates of parcel and plot area was recorded on the 10 selected holdings in Groups II and III.
(iii) Measurements using compass and measuring tapes were recorded on the 5 selected holdings in Group I.
(iv) Measurements by use of GPS equipment were recorded for all the 15 holdings in the EA i.e for all the Groups I-III.
All the four measurements had to be independent.

The land area measured per holding selected for the PCA was limited to that one within the selected EA and included:

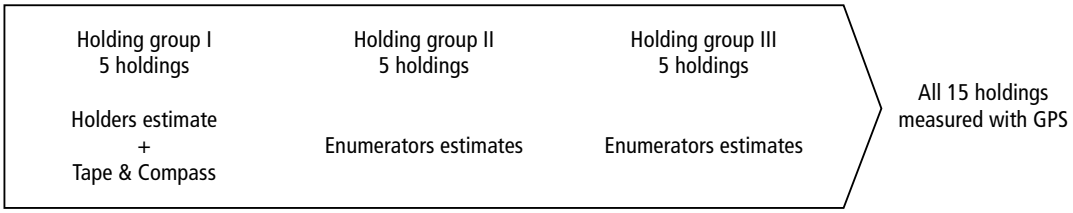
- The total area of the holding.
- Pasture land; and

- The area of agricultural parcels[3] and plots[4] under various crops.

The holdings in the EA were divided into three (3) groups/strata each with five holdings. The reason for this stratification of holdings was that the different methods for area measurement should be applied to the holdings independently. Secondly, as the compass and tape take a long time, it was considered necessary to limit it to only five holdings which were then also measured by the GPS tool for comparison. The following scheme illustrates the three selected holding strata and which methods should be applied to each:

3: A Parcel is any piece of land that is part of the holding, but is entirely surrounded by other land, water, a road, forest, etc, not forming part of the holding. This implies that a parcel is part of a holding that is physically separate from other parts of the holding. A holding is made up of one or more parcels.

4: A Plot is defined as a piece of land within the holdingand within a parcel on which a specific crop or a crop mixture is grown. A parcel may, therefore, be made up of one or more plots.



The area measurements and/or estimates for both parcels and plots were carried out in the following sequence:

- While walking around the holding to decide on the parcel boundaries and the number of plots to be found on the parcel, the holder's/respondent's area estimate were to be recorded in the appropriate form for the five selected holdings for Group I.
- The Enumerator would make his eye estimates and record it on the appropriate forms for the ten selected holdings in Groups II and III.
- The Enumerator would take measurements using compass and measuring tape (traversing) on five selected holdings in Group I, and record the measured results (meters and degrees) for each of the sides in the parcel/plot that was measured. Results were then recorded (bearings and lengths). Thereafter, the Enumerator would calculate the measured area and the closing error using the programmable calculator and record the final results.
- The Enumerator would do the area measurement using the GPS equipment for all parcels and plots in Group I –III and record it in the same forms.
- Finally the Supervisor and/or the team from UBOS/MAAIF (Ministry of Agriculture, Animal Industry & Fisheries) cross-checked some selected parcels and plots by measuring, using GPS equipment.
- The Holders'/Respondents' eye-estimates were made on different holdings to ensure independence of the two. Further, the actual measurements were to be carried out after the eye-estimates again to ensure independence. In both cases the eye-estiamtes would not be affected.

2.5 Use of the GPS Equipment in the Pilot Permanent Agricultural Statistical System (PASS)

The Uganda Bureau of Statistics (UBOS) in co-operation with the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) have been conducting pilot agricultural surveys since 2004 to test a proposed system for collecting annual agricultural statistics. In these surveys the GPS equipment has also been used for the estimation of crop areas.

3. Lessons Learned in the Use of the GPS Equipment

Following the above-mentioned work, several lessons have been learnt as outlined below, especially from the Pilot Census of Agriculture (PCA) 2003, the subsequent Permanent Agricultural Statistics System (PASS) and the on-going Uganga Household Survey (UNHS) 2005:

3.1 Results from use of GPS and traversing during the PCA, 2003

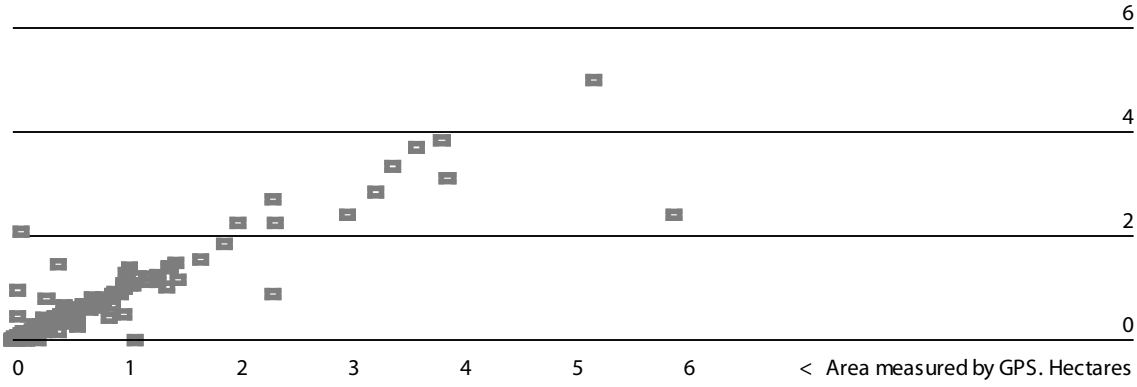
The experimental design of the PCA allowed the comparison of the results of area measured with GPS equipment, by traversing with tape and compass and even by eye estimates by the holders and enumerators on a large number of holdings and in different topographic and vegetation cover conditions.

Initially problems with the level of accuracy were expected when the objective was to measure the area of parcels and plots. Experience on the ground, was however more positive. Basically the results of GPS measurements of areas reveals variances around the assumed most correct area figure i.e. the figure based on accurate traversing.

Comparative study of measurementmethod for Parcels

1. There were 430 observations where areas of parcels were measured both with GPS tool and by traversing (tape & compass). A paired T-test (see figure 3.1) of this set of observations reveals that there is no significant difference between the results of the two methods concerning parcels measured during the PCA filedwork 2003.

Figure 1. Comparison of Parcel Area measured by GPS and area measured by traversing. PCA 2003



There are a number of outliers. However, the explanation about what caused them was unfortunately, not ascertained.

Comparative study of measurement method for Plots

A total of 1,004 plots were found where area is both measured by the GPS tool and by Traversing (measured area both for GPS and Traversing >=0). The area size of most of the measured plots is very small and in order to reveal possible differences between measurement of small and larger plots during the statistical testing, the dataset for plots was divided into

2 strata; Stratum 1 with plot areas at least 0.5 hectares (N=70) and Stratum 2 with plot area size less than 0.5 hectares (N=934). Thereafter a paired T-test comparing the areas obtained by traversing and use of GPS tool was conducted for the two strata of plot area size. The results of these T-tests are presented in Tables 3.1- 3.3

Table 1:

Paired Samples Statistics of Plot Areas

		Mean	N	Std. Deviation	Std. Error Mean
Stratum 1	Traversing	8.9251	70	14.37497	1.71814
	GPS	7.8983	70	14.29725	1.70885
Stratum 2	Traversing	0.1441	934	0.57584	0.01884
	GPS	0.0894	934	0.09383	0.00307

Table 2:

Paired Samples Correlations of Plot Areas

	N	Correlation	Sig.
Stratum 1	70	0.897	0.000
Stratum 2	934	0.121	0.000

Table 3:

Paired samples Test of Plot Areas

	Paired Differences					T	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Stratum 1	1.0269	6.49338	0.77611	-0.5214	2.5752	1.323	69	0.190
Stratum 2	0.0547	0.57209	0.01872	0.0180	0.0914	2.922	933	0.004

The results from the paired T-test in Table 3.1 indicates that traversing of the plots that are more than 0.5 hectares, gives a slightly larger area per plot compared to the same plot area measured by GPS equipment. This tendency seems to be the same when plots with area size less than 0.5 hectares are measured. However, since the questionnaire only allowed for filling in of hectares with 2 decimal places, this size group of small plots may have been disturbed by rounding-routines for the smallest areas measured i.e. those plot areas that were less than 0.01 hectares but rounded up and recorded as beeing equal to 0.01 hectares by the Enumerators.

Results for a combined sample of all plots are shown in Tables 3.4 to 3.6 and Figure 3.2. Using this sample in a paired T-test reveal, as for parcels but now also on the smaller plot areas, that there is no significant difference in the measured results of the two methods.

Table 4:

Paired Samples Statistics for all Plots

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	AREA_traversing	0.7374	1030	4.36468	.13600
	AREA_GPS	0.6178	1030	4.19330	.13066

Table 5:

Paired Samples Correlations for all Plots

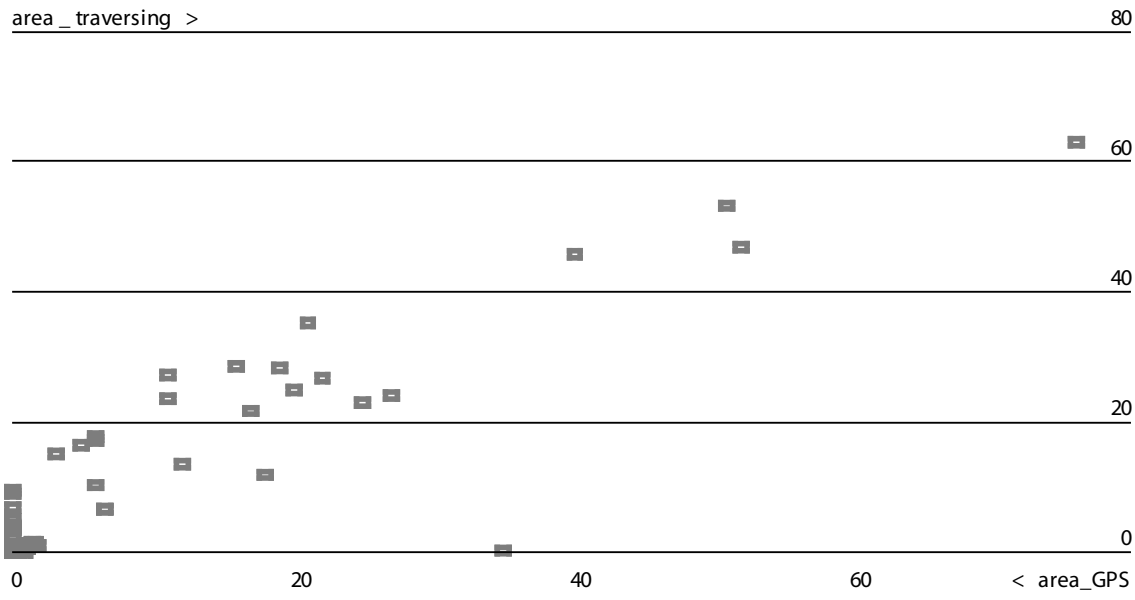
		N	Correlation	Sig.
Pair 1	AREA_traversing & AREA_GPS	1030	0.914	.000

Table 6:

Paired Samples Test for all Plots

		Paired Differences					T	Df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	AREA_ traversing-AREA_GPS	0.1196	1.78444	0.05560	0.0105	0.2287	2.151	1029	.032

Figure 2. Comparison of Plot Area measured by GPS and area measured by traversing. PCA 2003



The results with plots are still unclear and inconclusive, especially as subsequent work in PASS shows that measurements with the GPS tool are inconsistent especially for small plots. As small plots form a high percentage of planted area for a number of crops there is need for more research.

Results of Comparison of Time Use during PCA

1. Time use for the different measurement methods was recorded by the enumerators during the fieldwork of the PCA. For all observations recorded, the average timeuse for traversing with tape and compass was three times as long per holding as when GPS equipment was used (Table 3.7).

Table 7:
All observations of time used. Traversing, Use of GPS and Enumerator's Estimates. PCA 2003

		Traversing	GPS use	Enumerator's estimate
				Observations
N	Valid	302	538	448
N	Missing	476	240	330
				Minutes used
Mean		153.9	55.6	46.1
Median		97.0	48.0	37.5

At the beginning of the PCA, there was confusion on how and where to record the time taken, especially for traversing which took a long time. This contributed greatly to the missing observations but was subsequently clarified.
A subset of all observations was selected in order to compare observations about time use on those holdings where both GPS equipment measurements and traversing with tape and compass was conducted. A paired T-test for this subset of 191 holdings reveals that time use for traversing was as much as 3 hours and 23 minutes or 3.5 times as much as when GPS equipment was used (Table 3.8).

Table 8:
Comparison between time use for traversing and use of GPS. Paired T-test Samples Statistics. PCA 2003

	Mean minutes used	Comparable observations (N)	Standard. Deviation	Standard error for the mean
Traversing	203.1	191	185.4	13.4
GPS use	57.8	191	34.1	2.5

It should however, be noted that the mean minutes for traversing in Table 3.7 (153.9) is considerably different from the 203.1 minutes shown in Table 3.8. The reasons for this difference were, unfortunately, not explored. However, even this is still three times the time for using the GPS tool. Therefore, it can be concluded the GPS equipment is a far more time-efficient method/tool than the tape and compass measured in terms of average time use per holding.

Comparison of costs of instruments

Even simple handheld GPS tools are relatively expensive tools. The GPS equipment model used in the PCA was a Garmin 12 channel receiver with an approximate price of USD150 per unit (2003 prices). During the PCA fieldwork, three enumerators shared two GPS tools. With good logistics, cost efficiency could be improved by letting even more enumerators share the same tools.

The use of batteries turned out to be high as it was agreed to change batteries when approximately 2/3 of the energy was used. Since each GPS tool uses four high quality AA batteries, the costs for power supply was considerable. The recommended batteries cost an equivalent of US$1.25 per pair compared to the more common ones which cost about USCents25. Clearly, this cost could be reduced by giving the equipment to the staff only when they are ready to carry out the area measurements. Also use of re-chargeable batteries may reduce the costs. The enumerators were instructed to switch off the equipment whenever not in use. It was however, not easy to know how well they followed this instruction.

For further work it should be experimented with rechargeable batteries as a more cost efficient option. However not all areas in Uganda have stable power supply and recharging can give some logistical problems.

Two GPS device were lost during the project period due to unfortunate civil unrest in the enumeration areas. Such losses and cost will have to be expected to occur even more frequently in a full census since all districts shall be included.

The price of high quality tape and compass equipment is approximately 25 USD and 100 USD (compass including jacket) respectively. In addition a fairly expensive programable calculator is necessary to calculate areas captured by traversing. The total price is therefore not so different from the price of a GPS tool. On the otherhand, battery cost are zero for tape and compass.

Other General Observations

The way the GPS equipment was set up for the PCA, the area of each parcel and plot was calculated directly in square meters. Therefore, the value had to be converted to hectares (by dividing by 10,000) with two decimal places before information could be recorded in the appropriate questionnaire. Some enumerators had problems converting from Square Meters to Hectares. Others had recorded the values in square meters directly on the forms and this caused some confusion in the data entry/data cleaning process. Why did you have the enumerators doing the conversion? The form should have a place for the enumerator to record the square meters and let someone else do the conversion. Space on the questionnaire is limited and filling in Sq. Mts will need a very large range and hence many boxes. However, in subsequent work e.g. PASS, enumerators were given more training and are copying better.)

During the PCA fieldwork it turned out to be necessary to repeat and further drill the routines for using the GPS. This was an indication of lack of proper training. Further, unfortunate changes of the setup of the instruments accidentally occurred and had to be corrected. However, in the end most of the enumerators managed to record both areas and coordinates according to the instructions.

Since the GPS equipment is fast and easy to use compared to traversing with tape and compass, in some cases the enumerators only conducted GPS measurements and in spite of their instructions they did not follow up with the requested but cumbersome traversing of the same plot. It is also assumed that using the "high tech" GPS adds importance and status to the enumerator work as he/she visits the holders.

During area measurement the experience was that positioning from between 5 to 8 satellites for each observation were received. The expected accuracy when using a hand held GPS-tool without any corrections based on additional fixed ground

stations or WAAS techniques is better than +/- 15 meters. This accuracy is acceptable when the objective is to geo-reference the holding for statistical use.

During the fieldwork, problems were found with using the GPS tools on plots and parcels where the tree canopy cover is dense. In addition, there were problems with area measuring in very steep terrains due to the difference between actual area and horizontal projections. Also struggling with some "shadow" effect when receiving of signals from satellites in hilly terrain caused problems. A possible improvement could be to equip the GPS tool with an external antenna device when used under extreme conditions. This is possible for the GARMIN 12XL tool.

Farmers eye-estimates of area size both for parcels and plots and seem to overestimate the size of the areas compared to values obtained from use of GPS and traversing technique.

3.2 Experience from PASS

In the PASS there has not been any comparison with other methods of area measurement, however the exercise has provided further experience in the use of the GPS equipment.

Step by step instructions for setting up the GPS tool

The GPS tool measurement accuracy is sensitive to the set up of the instrument and possibly to battery status. Therefore detailed instructions on how to set up the GPS GARMIN 12 (or 12XL) device have been made for the pilot PASS 2004. *(For practical use of the GPS and for more information on the set-up refer to the GARMIN manual (hardcopy or www.garmin.com) and UBOS 2004a).* A few examples are given below.

The area calculation should be recorded as hectares with 3 decimals (i.e. 10 square meters is the smallest area that can be recorded) in the PASS questionnaire. The GPS should be set up so that areas are calculated in square meters. The enumerator must take the readings of square meters area from the GPS and divide this value on 10,000 to get the area in hectares. Finally this value of hectares with three decimals should be recorded in the PASS questionnaire.

When using the GPS, the tool records and stores the geographical position at a specific interval of times based on signals from satellites that are received continuously as long as the device is switched on and has free sight to the sky.

The time interval that the GPS should use between each observation or position is recorded in the GPS memory should be correctly set up to 00.00.10 seconds. There has however, been proposals to reduce this time interval to cater for the small plots.

Finally, during the measurement, the speed of movement should not be too fast and the staff should stop in corners (for at least 15 seconds).

Costs of the GPS Equipment

Unfortunately, the Germin 12 and 12XL models used for PASS have cost US$470 compared to the US$150 for those used in the PCA. Long life batteries should be used (e.g. Duracell or Energizer AA batteries). However, it was established that batteries could be changed when they reach 75% used. This compares to 2/3 recommended in the PCA. Thus a reduction in overall costs. How long the batteries take before replacement, depends on how organised the field staff are, especially switching off the equipment whenever it is not in use.

Training of Field Staff

During the PASS, field staff training on the use and practice of the GPS equipment was increased considerably, compared to the PCA.

Consistency of Measurements

During the PASS and the on-going Uganda National Household Survey (UNHS) inconsistencies have been observed whereby with repeated measurements different equipments, and even the same equipment, give different readings for the same area; especially for small areas. These are unfortunately common and at times the differences have been quite wide. This is being investigated. If the accuracy rate is around plus/minus 15 meters, say, then the smaller the plot the larger the possible error. The best thing to do would probably be to repeat the measurements for plots smaller than a predetermined size and take an average.

4. Conclusions

The results from the PCA indicate that the area measurements by the GPS equipment and those by the compass and tape are very close – for parcel areas there were no statistically significant difference between the results of the two methods. Considering that the GPS equipment is much faster, this indicates that there is a potential for the GPS equipment for agricultural area measurements. Further work during the PASS collaborates some of these findings. However, as the differences for small plots were not conclusive, a lot more research work needs to be carried out for small polts. This includes trying to find the critical plot sizes above which the results are acceptable. Secondly, efforts need to be made for cheaper GPS equipment and running costs or at least more efficient use. Thirdly, there is need for more thorough training of field staff and proper setting of the equipment. Fourtly, more study is required on the variability and consistency of the equipment under more scientifically designed and closely supervised conditions. It is useful to compare different makes/models of the equipment. Finally, special studies concerning effects of steep slopes and under tree and cloud cover should also be conducted.

5. Further work and new possibilities for statistics

Combination of digital thematic maps, digital administrative boundaries and geo-referenced statistical information opens for spatial analyses of data. However, before such data can be used in Geographical Information Systems (GIS), a long pro-

cess of data capture, geo-referencing/geo-coding, scanning and digitalization is required. Since geographical information will be found in different organizations in Uganda, it is crucial for common use to agree upon standards and formats.

By introducing geo referencing (coordinates) and geocoding (administrative division unit code) to statistical information of agricultural holdings sampled during survey and censuses and at the same time introduce similar coding for business and industry surveys/listings, new possibilities for spatial analyses of data occurs. The statistical information can also be combined with other sources of digitalized geographical data such as thematic maps available at the The Uganda National Biomass Study including digital main road net, water courses, land cover classes etc.

The use of the GPS tool also enables the use of point sampling which is a form of area sampling. Points can be randomly identified, once the enumerator finds the point using the GPS tool, the next step is to construct the holding around it and use Probability Proportional to Size (PPS) to estimate the land area.. This needs to be investigated.

References:

GARMIN manual (hardcopy or Web-page: www.garmin.com)

Ministry of Agriculture (1964). Uganda Census of Agriculture 1963/65; 4 Volumes

Ministry of Agriculture, Animal Industry & Fisheries (1993). National Census of Agriculture and Livestock 3 Volumes

Muwanga-Zake, E.S.K. (2003). Experiments in Yield Estimation in Uganda; Paper presented at the 54th Session of the International Statistical Institute, Berlin, Germany

Uganda Bureau of Statistics (2002). Report on the Pre-Test for the Uganda Census of Agriculture and Livestock conducted in Masaka District in June/July 2002

Uganda Bureau of Statistics and Statistics Norway (2003a); Paper on the Results From the Pilot Census of Agriculture, 2003: GPS Equipment For Agricultural Statistics Surveys

Uganda Bureau of Statistics (2003b). Use of the GPS Equipment In Agricultural Surveys: Uganda's Field Experience: A Paper Presented at AFCAS & Technical Workshop On Rural Data For Policy Support, Best Practices And Emerging Methods In Agricultural Statistics; Yaoundé, Cameroon; 23rd – 30th October, 2003

Uganda Bureau of Statistics (2004a). Report of the Pilot Census of Agriculture, 2003

Uganda Bureau of Statistics (2004b). The Permanent Agricultural Statistical System – A Proposal by Dr. E.S.K. Muwanga-Zake, National Long-Term Consultant

Uganda Bureau of Statistics (2004c). Permanent Agricultural Statistics System Enumerators' Manual.