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Adoption and impacts of modern sorghum and pearl millet varieties in Northern Nigeria

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Abbreviations and acronyms

ADN	Agro-Development Nigeria Ltd.
ADP	Agricultural Development Project
ATE	Average Treatment Effect
ATT	Average Treatment of the Treated
CDF	Cumulative Density Function
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	FAO STATistics
FCFA	Franc de la Communauté Française Africaine
FOS	Federal Office of Statistics
HJRBDA	Hadejia Jama’are River basin Development Authority
IAR	Institute of Agricultural Research
ICMV-IS	ICRISAT Millet Variety – ICRISAT Sahelian
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICSH	ICRISAT Sorghum Hybrid
ICSV	ICRISAT Sorghum Variety
IER	Institut d’Economie Rurale
INRAN	Institut National de la Recherche Agronomique du Niger
JARDA	Jigawa State Agricultural and Rural Development Authority
KNARDA	Kano State Agricultural and Rural Development Authority
LATE	Local Average Treatment Effect
LCRI	Lake Chad Research Institute
NAERLS	National Agricultural Extension and Liaison Services
NAEZP	North-East Arid Zone Development Programme
NALDA	National Agricultural Land Development Authority
NCS	National Consumer Survey
NCSRP	Nationally Coordinated Sorghum Research Project
NCVRC	National Crop Variety Release Committee
NG	Nigeria
NGO	Non-Governmental Organization
NN	Nearest Neighborhood matching
NSS	National Seed Service
OFAR	On FArm Research
PSM	Propensity Score Matching
SAMSORG	SAMaru SORghum
SOSAT	SOuna SAnio Tardif
USD	United States Dollar
WASIP	West African Sorghum Improvement Program

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Summary

This paper uses a data set of 1105 households from 119 villages living in 6 states of Northern Nigeria (Borno, Jigawa, Zamfara, Katsina, Kano and Yobe) to assess the current and potential adoption rates as well as the impact of modern sorghum and pearl millet varieties released since 1996 in Nigeria. Varieties under investigation include modern sorghum varieties and hybrids namely ICSV 111, ICSV 400, ICSH 89002 NG, ISCH 89009 NG, and SK 5912 and pearl millet varieties namely SOSAT C88, LCIC 9702, GB 8735 and ZATIB. Adopters are defined as those having planted at least one modern variety of pearl millet or sorghum. Results showed that the current adoption rates for modern pearl millet varieties is estimated to 34.8% of the farmers and that of modern sorghum varieties is estimated to about 22.9%. In terms of area planted, modern pearl millet varieties account for 25% of the pearl millet area and 17 % of the sorghum area planted. The pearl millet variety SOSAT C88 is largely adopted by farmers accounting for about 95% of area planted with modern pearl millet varieties. For sorghum, ICSV 400 and ICSV 111 are the most widely adopted accounting for 8.46% and 7.07% of area cultivated to sorghum respectively. They both account both for more than 95% of area planted with modern sorghum varieties. Over all, extrapolating from FAO statistical data, it can be estimated that in Northern Nigeria, modern pearl millet varieties occupy 1,154,261 ha and modern sorghum varieties about 1,200,532 ha.

Using the treatment effect estimation framework, the potential adoption rate for modern pearl millet varieties is estimated to 58.60% with an adoption gap of 23.8%, whereas that of sorghum is limited to 27.24% with a gap of 4.33%. Potential for increasing adoption of modern pearl millet varieties is still high whereas that of sorghum varieties is limited based on awareness or promotion.

Matching and econometric methods indicate that the impacts of modern pearl millet varieties on yield are estimated to between 88 to 157 kg/ha between adopters and matched non-adopters. The estimated impacts of adoption on per capita total gross income (household revenues) are 34 to 52% higher for adopters than matched non-adopters. Similarly, the estimated impacts of adoption of modern pearl millet varieties are 48 to 101% higher for adopters and matched non-adopters. The quantity of cereals available per capita is estimated between 127 to 231 kg/person/year for adopters versus matched non-adopters. There are however no significant differences based on per capita total wealth, number of hungry months and per capita expenditures. Using simple economic surplus approach, it is estimated that the total net present value of gross benefits derived from pearl millet research and development is about US$8,833,216 from 1996 to 2009. The situation is different for modern sorghum varieties where no differences between matched adopters and non-adopters were found based on average yield, total value of production, total value of production and total wealth. With regard to food sufficiency, no differences were found in the average cereal production per adult equivalent or the number of hungry months. The impact of modern sorghum varieties was therefore found to be limited. Poor households have benefitted more from improved pearl millet varieties than relatively wealthier households. In effect, the last quartile of poor wealthier households is deriving on average 252 kg/ha more than the other wealth classes. As for sorghum, there is no evidence of poverty impacts.

Farmers expressed their preferences for traits of selected pearl millet and sorghum varieties. The variety SOSAT C88 is preferred for early maturity, insect tolerance, grain color, cooking time, and head filling and is disliked for its low fodder yield, poor storability and shorter head. The local pearl millet varieties in general are preferred for long head and large stalk but disliked for their high susceptibility to insect attacks, late maturity, low grain yield, small grain size, grain color, high cooking time. As for sorghum varieties, the variety ICSV 400 is preferred for its insect tolerance and early maturity, high fodder yield, higher selling price, but is disliked for low drought resistance, shorter head, and small stalk. The variety ICSV 111 is disliked for its low selling price, shorter head, lower fodder yield, and is preferred for its insect tolerance and early maturity. These characteristics should be taken into account when designing/developing pearl millet and sorghum varieties that suit farmers' needs.

There are potential for increasing uptake of pearl millet varieties in Nigeria and especially SOSAT C88. This suggests that a large impact can be realized by developing and implementing a successful dissemination project with a strong seed multiplication and delivery component. Similar potential are limited for sorghum varieties released less than 20 years ago. Further investment in the exposure and promotion of modern sorghum varieties may not warrant its costs. These varieties face significant constraints to adoption. Consistent with farmers' perception of low productivity gains and social constraints, adoption of current modern sorghum varieties remains low and farmers are in the stage of dis-adoption. Therefore, there is a need for significant fresh investment in sorghum research in Northern Nigeria to lift those constraints. Similarly, further research is needed for pearl millet varieties. SOSAT C88 is at date the most preferred variety. However, farmers dislike its lower fodder yield, poor storability and shorter

head. Further research is needed to bring these traits into SOSAT C88 in addition to the development of other pearl millet varieties that suit farmer' needs.

Yield gains estimated from this study are still limited even for pearl millet varieties and in this case about 10% between matched adopters and non-adopters. This trend is observed in many Sahelian countries where productivity gains from modern open pollinated varieties are not higher than 20% everything being equal between modern and local OPVs. There are potential with hybrid varieties where breeders can achieve higher productivity gains. Research in the next decade should focus on hybrid research where it would be easier for farmers to attain higher productivity gains and higher profits and for the private sector to enter the seed industry and make it more sustainable.

Varieties reported by farmers are unlikely to be of true type because of cross pollination as in the case of pearl millet and therefore will not express the full genetic potential. Differences between the potential yields of modern varieties reported by scientists and those reported by farmers raise serious doubts on the genetic purity of the cultivars. The yield gaps are huge to be explained solely by the weak crop management. After ICRISAT technology exchange work ended in 2002 in Northern Nigeria, there has been little efforts to maintain breeder and produce foundation seed of the studied varieties. Seed renewal rate by farmers is very low i.e. every 9 years on average. With a weak seed system, it is unlikely that farmers had access to good quality seed even if they are willing to pay for. Farmers mostly source the seed from village markets. Seed quality is a major concern. There is a need for fine tuning the current impact assessment research by improving the identification of varieties. The use of finger printing methods or assessment of types by breeders may be necessary to ascertain the type of varieties and its adoption.

Key words: Technology adoption, Poverty Impacts, Average Treatment Effect, Sorghum, Pearl Millet, West Africa

I - Introduction

The role of agricultural technologies and innovations in alleviating and reducing poverty and contributing to economic development has been well documented (Just and Zilbermann, 1988; Binswanger and von Braun, 1991). The benefits from adopting new technologies and innovations are viewed directly through productivity increases that can translate into higher farm incomes. Indirect benefits can accrue to other farmers and consumers through lower food prices, increased in food availability, accessibility and consumption and potentially non-farm employment (de Janvry and Sadoulet, 2001). This is likely to be true in the dryland regions of West Africa where sorghum and pearl millet are the major staple cereals and where donors and governments' investments in the development and dissemination of sorghum and pearl millet varieties.

Sorghum and pearl millet are the major staple foods for millions of smallholder farmers in the semi-arid tropics of West Africa. Farmers plant about 45 million ha of cereal crops (sorghum, pearl millet, rice, wheat and maize) with production estimated to about 54 million tons of cereals in 2006-2009. Sorghum and pearl millet alone account for 68% of area cultivated with cereals and 55.32% of cereal production. Research and development interventions resulting in higher uptake of modern sorghum and millet varieties by farmers will likely lead to increase in income, food security and welfare of millions of farmers.

Nigeria is the cereal basket of West Africa with cereal production accounting for more than half the total cereal production. Sorghum and millet account for 65% of total cereal area and 62% of total cereal production. These crops are grown in the harsh semi-arid tropics of Nigeria where inadequate rainfall and lack of irrigation make production of other cereal crops difficult to sustain. The North of Nigeria is plagued with recurrent droughts and varieties that can escape or tolerant to major biotic and abiotic stresses such as drought as well as having the cooking characteristics sought by farmers are likely to be adopted.

In the past two decades, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) along with partners such as the Institute of Agricultural Research (IAR), the Lake Chad Research Institute (LCRI), Non-Governmental Organizations (NGOs), Seed companies and rural development projects have invested in the development and dissemination of pearl millet and sorghum varieties in Nigeria. Two sorghum varieties (ICSV 400, ICSV 111), and 4 sorghum hybrids (ICSH 89001 NG, ICSH 89002 NG, NSSH 91001, NSSH 91002) were released and four pearl millet varieties (SOSAT C88, GB 8735, LCIC 9702 and LCIC 9703) were also released.

Since 1996, recent data from FAO statistics support the anecdotic evidence that productivity has increased and farmers have expanded the area cropped with pearl millet and sorghum. Using FAO data, area and yield have increased significantly in West Africa and in Nigeria in particular. From 1984 to 2009, increases in production are largely explained by increased in both area and yield. Pearl millet yield is estimated to have increased by 1.22% and area cultivated by 1.68% resulting in increased production of 2.90%. Similarly, sorghum yield is estimated to have increased by 0.76% and area cultivated by 1.81% resulting in increased production by 2.57% per annum. Productivity growth may have been explained by both uptake of modern varieties and use of other inputs such as fertilizers.

This is supported by few studies indicating high uptake of modern pearl millet and sorghum varieties. In 2005, it is estimated that 56% of farmers surveyed in 5 states of Nigeria (Yobe, Borno, Kano, Katsina and Jigawa) are using modern sorghum varieties and about 47% modern pearl millet varieties. The most widely adopted varieties were ICSV 400 for sorghum and SOSAT C88 for pearl millet. Adoption of ICSV 400 is hypothesized to have been driven by its malting property and for pearl millet, its early maturing trait (Youssouf et al., 2005). These findings though with relatively less magnitude, corroborate with earlier studies on sorghum (Atala et al., 1999, Macaver, 2002) and pearl millet (Kristjanson et al., 2001). It is estimated that more than 80% of households in Northern Nigeria are using some of the technologies. Improved sorghum varieties ICSV 400 and ICSV 111 are grown in 30% areas of the Jigawa region in Nigeria. Pearl millet variety SOSAT C88 is flourishing in that part of Nigeria - and is grown by over 10,000 farmers (Kristjanson et al., 2001). Factors affecting adoption of ICSV 111 and ICSV 400 were identified by Ogungbile et al., 2002 and were due to both household socio-demographic profile and technological characteristics.

Macaver (2002) assessed the economic impact of sorghum research and extension in Katsina State in Northern Nigeria. Using an economic surplus model, the internal rate of returns was estimated to about 62% and the net present value of investments were estimated to 17 million Naira. Various sensitivity analyses show high social rates of returns to the sorghum project. However, consumers capture 188% of the project gains and producers lose -88%. Factors affecting adoption were maturity, disease resistance, variety promotion and formal education of producers.

Though very informative on the potential adoption of sorghum and pearl millet varieties, studies on the adoption and impact of pearl millet and sorghum varieties have not been systematic enough in the sampling scheme and methodologies. Those studies have been conducted in environments where varieties have been introduced (localized sampling and poorly representative samples). In addition, none of them has specifically addressed the impacts of sorghum and pearl varieties on farmers' livelihood outcomes such income and food security, ie poverty impacts. This study combines the matching and econometric methods to assess the levels of current and potential adoption rates of sorghum and pearl millet varieties, identify the drivers of adoption of modern varieties and finally, assess the impacts of adoption on household livelihood outcomes. The following section presents the role of sorghum and pearl millet in the livelihood of Nigerians. Section 3 highlights the study region and section 4 discusses the methodology. Section V presents the results and Section VI concludes.

II - Sorghum and pearl millet in the livelihood of Nigerians

2.1 - Sorghum and pearl millet supply

In Nigeria, sorghum and pearl millet account for 42.59% of cultivated area (19 million ha) and 54.05% of total cereal production (20 million tons) in West Africa. This trend is consistent in Nigeria and across many Sahelian countries. Sorghum and pearl millet account both for 66% of total area cultivated and 61% of cereal production in Nigeria. In Mali, Niger, Burkina Faso and Senegal, sorghum and pearl millet account in each country for over 78% of total cereal area and over 50% of total cereal production. Figure 1 depicts the trends on sorghum production, yield and area cultivated in Nigeria where one can observe 2almost distinct periods: a period of decline from 1960 to 1984 and a period of growth onwards.

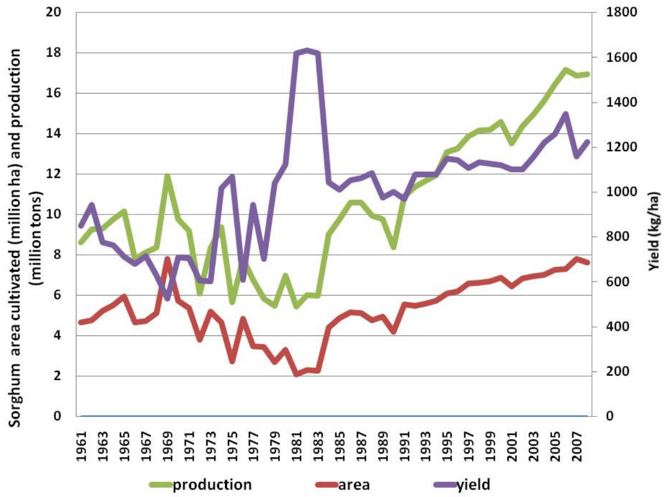


Figure 1. Trends in sorghum production, area and yield in Nigeria (FAOSTAT, 2010).

Since 1984, sorghum production increased by 2.57% as a result from yield increase (0.76%) and area increase (1.81%). Figure 2 depicts pearl millet trends in terms of area, production and yield. Same as the case of pearl millet, one can observe 2 periods: a period of decline and a period of growth. Since 1984, pearl millet production grew by 2.90% as a result of productivity growth (1.22%) and area increase (1.68%).

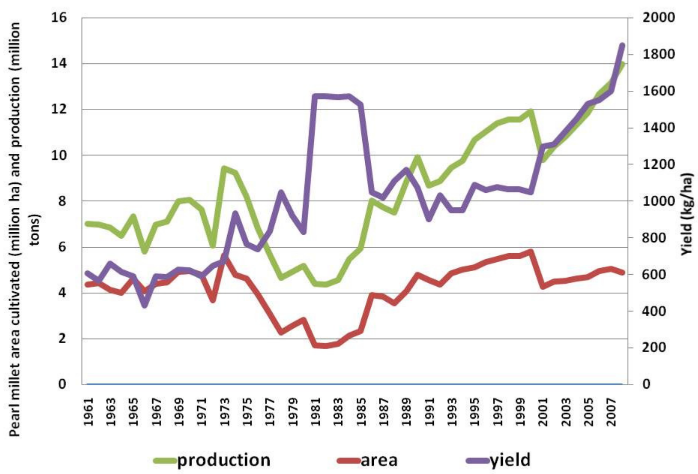
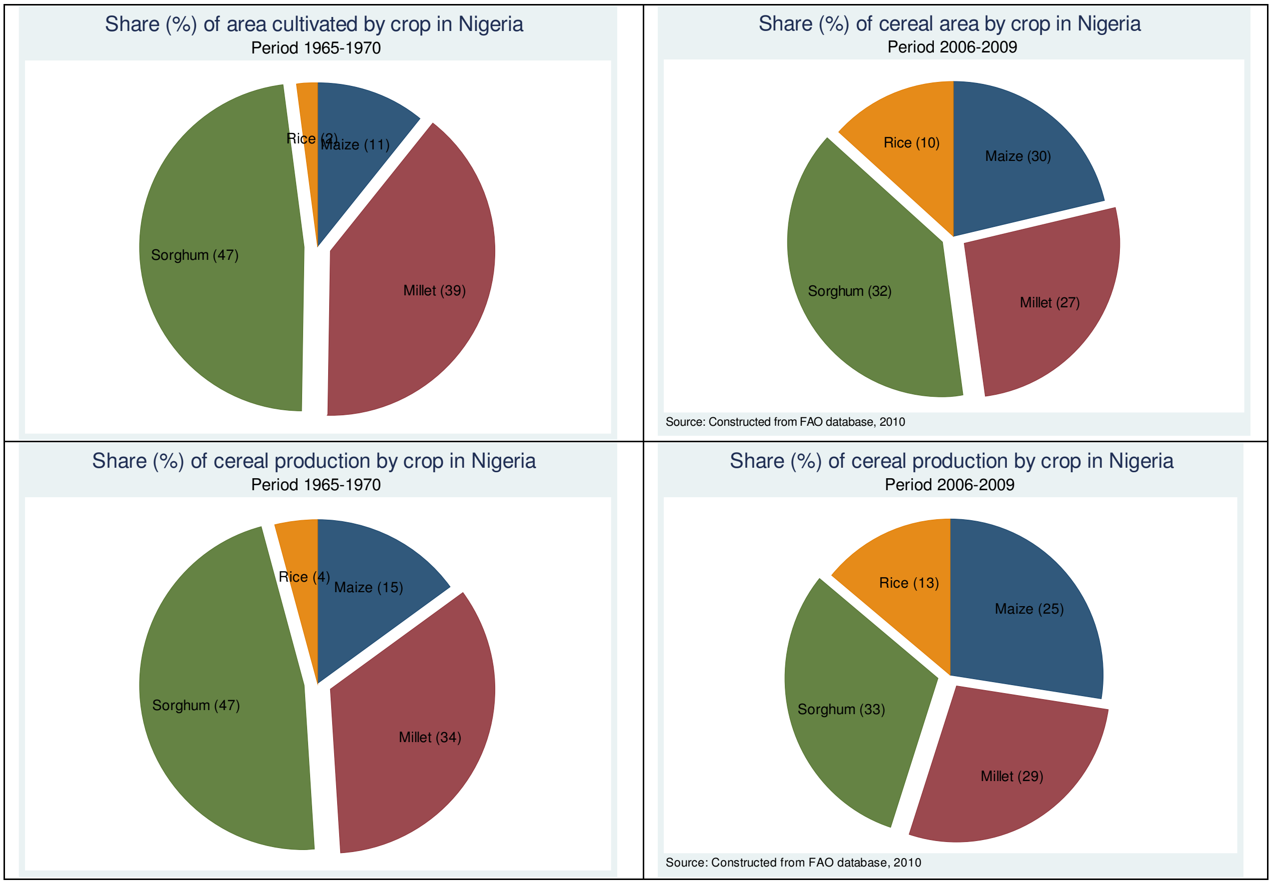


Figure 2. Trends in pearl millet production, area and yield in Nigeria (FAOSTAT, 2010)

Figure 3 shows the share of area cultivated by crop in 4 time periods. On average in 1965-70, sorghum accounted for 47% of area cultivated, followed by pearl millet 39%, maize 11% and rice (3%). However, on average in 2006-09, the relative importance of area covered by sorghum and pearl millet has decreased while those of maize and rice have increased. In 2006-09, sorghum accounts for 32% of cereal area planted followed by pearl millet (27%), maize (30%) and rice (10%). Cereal production follows the same trend.

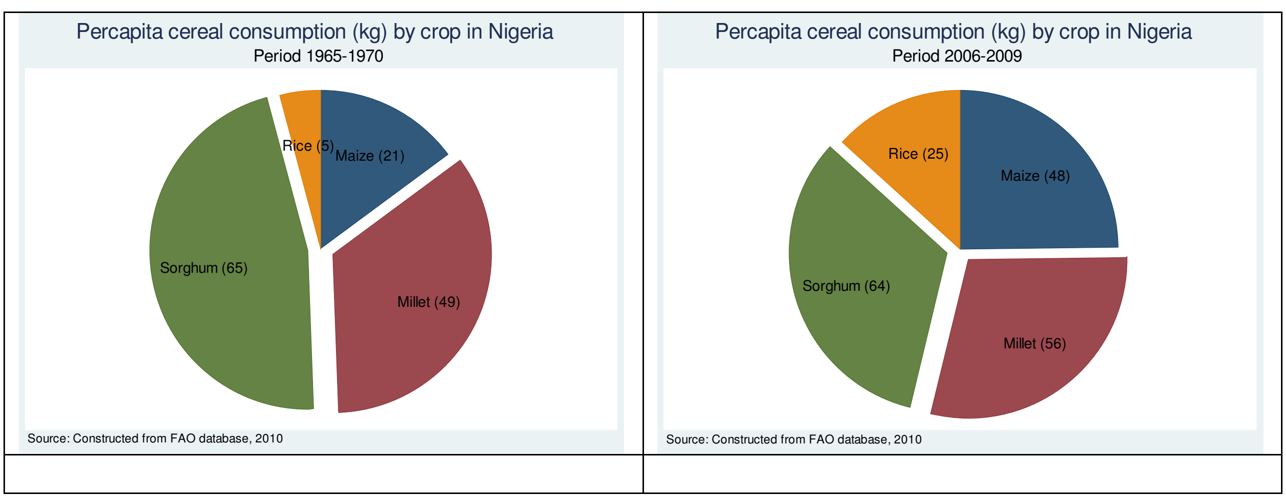
Figure 3. Share (%) of area cultivated and cereal production to cereals by crop in Nigeria from 1965-70 and 2006-09.



2.2. Sorghum and pearl millet consumption in Nigeria

Figure 5 below presents the per capita consumption of cereal by crop in 2 periods; 1965-70 and 2006-09. Per capita consumption of cereals has increased from a 140 kg/person/year to about 193 kg/person/year. Pearl millet and sorghum account for a large share of human consumption. It is estimated that pearl millet and sorghum account for % of cereal consumption in Nigeria.

Figure 4. Per capita consumption (kg) of cereals from 1965-70 and 2006-09 in Nigeria



It is estimated that among cereals crops (sorghum, pearl millet, rice and maize), sorghum and rice per capita consumption have increased. While maize consumption has remained virtually constant, rice consumption has increased from 5% in 1993-97 to 7% in 2003-07; and sorghum production has increased from 15% to 22% during the same period. In contrast, pearl millet consumption has decreased from 79% in 1993-97 to 70% in 2003-07 (FAOSTAT, 2009).

Table 1. Consumption shares of major cereals in Nigeria in 1965-70 and 2006-09

	Period			
Crop	*1965-70*	*1975-80*	1990-95	2006-09
Maize	*14.89*	*11.09*	31.57	24.86
Pearl millet	*11.09*	*36.93*	23.32	28.95
Sorghum	46.61	43.47	30.21	32.95
Rice	4.15	8.51	14.89	13.25

Source: Calculated from FAO data, 2010.

Using the most comprehensive household level survey, ie. a nationwide consumption survey (NCS) of the Federal Office of Statistics (FOS) in Nigeria, Akinleye et al. 2007 estimated the own and cross price demand and income elasticities for 7 goods including rice, millet, sorghum, yam, Garri, beans and maize and for 3 income groups mainly the low income earning households, the average income earning household and the high income earning households. Results showed that sorghum, millet and beans are the price elastic food items while other food items are price inelastic. Rice and yam are luxury food items for low-income households. Cross price relationships show that beans is complemented by other food items except yam; millet is a substitute for rice, guinea corn, yam and maize and maize is a substitute for millet, sorghum, garri and beans.

For mid-income earning households in Nigeria, rice, yam and millet are the luxury food items while sorghum and maize are the essential foods. The inferior foods are garri (cassava flour) and beans. Sorghum is price elastic and other food items are price inelastic. Rice would substitute millet, yam and maize, sorghum would complement rice, millet, garri, beans and maize and maize is a substitute for rice, millet, sorghum and garri.

For high income earning households, garri (cassava flour), beans and maize are inferior goods. The other food items are essential foods. Sorghum is price elastic while the other food items are price inelastic. Cross-price relationships show that beans would substitute for sorghum, yam and maize; millet would substitute guinea corn, yam and maize and yam would substitute every other food item (Akinleye and MAY Rahji, 2007).

III - Research and diffusion processes in Nigeria

3.1. Sorghum research and development

The West African Sorghum Improvement Program (WASIP) started in **1988** in Nigeria (ICRISAT, 1990) with the aim to production technologies to suit the Sahelo-Sudanian zone (600-900 mm rainfall). The major focus on crop improvement was the development of early maturing sorghum and hybrid varieties. Drought, poor seedling establishment, leaf diseases, leaf diseases, grain molds, long smut, head bugs and stem borers were the targeted traits. In 1988, three preliminary on station trials were conducted in Bagauda using 72 sorghum varieties selected based on the yield performance in Burkina Faso. Seventy-two varieties were tested of which 14 (including ICSV 401 IN and ICSV 111 IN) out-performed the local check SAMSORG 14.

In 1989, 20 early maturing varieties (less than 70 days to flower) and 20 medium maturing varieties (less 80 days) were evaluated in advanced replicated trials using local varieties of appropriate maturity at Bagauda research station. In the early variety trial, Nagawhite and ICSV 401 yielded more than 4 tons but the local check SAMSORG 3 about 2.83 tons. While Nagawhite had high grain yield but also had high tannin content unsuitable to human consumption. Four ICRISAT varieties (ICSV 401, ICSV 400 (M 24581), ICSV 247 and ICSV 111) were white-grain types suitable for human consumption.

As for hybrid sorghum, 17 advanced breeding lines were tested in a replicated yield trial at Bagauda. ICSH 507 ranked first in grain for the second consecutive years (5.5 tons/ha), followed by ICSH 780 (5.4 tons/ha) against the check ICSH 109 with 4.21 ton/ha. The same year, to start the promotion of sorghum varieties and hybrids, ICRISAT conducted a training course (4-9 September 1989) on Sorghum Hybrid Seed production for the benefits of the national research institutes, seed producing agencies and private large firms interested in seed production. In addition a large field day (25-29 September 1989) was organized including representative from Benin, Cameroon, Ghana, Niger, Chad and Nigeria and a national .workshop (4-6 December 1989) on “Industrial utilization of sorghum: current status and potential” was held in Kano, Nigeria.

In 1990,18 advanced hybrids were tested in replicated trials and the hybrids ICSH 89001 NG and ICSH 89002 NG yielded 6.26 ton/ha and 5.74 tons/ha more than the checks ISCV 111 (4.83 tons/ha) and SAMSORG 3 (3.68tons/ha). Eighteen (18) varieties were tested and ICSV 111 and ICSV 400 had the highest yields (5.13 ton/ha and 4.81 ton/ha respectively) more than the local checks Gaya early and SAMSORG 14 with 3.91 ton/ha and 2.09 ton/ha respectively. Several samples of ICSV 400 were provided to Breweries to test for testing and found its excellent malting properties (ICRISAT 1990).

In 1991, through 35 advanced sorghum hybrids tested at Bagauda, 2 hybrids (ISCH 89002 NG and ICSV 89001 NG) high performed the local checks. Parental lines of the 2 hybrids were supplied to Pioneer Hi-Bred Seed Nigeria Ltd and experimental seed production started. On farm testing of hybrids and varieties were carried out by the Kano State Agricultural and Rural Development Authority (KNARDA). In addition bulk quantities were provided to Hadejia Jama’are River basin Development Authority (HJRBDA), agro-Development Nigeria Ltd (ADN) and Guiness farms Nigeria Ltd. Screening tests at the University of Ibadan, identified ICSV 400 as having acceptable levels of malting quality compared to SK 5912 (ICRISAT, 1993).

In 1992, the Nationally Coordinated Sorghum Research Project (NCSRP) of Nigeria initiated yield and adaptive trials of elite varieties and hybrids in all the sorghum growing areas to enable the Variety Release Committee to make appropriate cultivar releases and recommendations. ISCH 89009 NG was the highest yielding hybrid variety and ICSV 400 was the highest among composites on trials conducted by KNARDA. KNARDA conducted food tests to find that ICSV 111 was the most preferred. Similarly, JARDA tested the same cultivars and still found ISCH 89009 NG to yield the highest. To promote hybrids and varieties, more than 1 ton of seed of elite varieties was produced by ICRISAT and supplied to Agricultural Development Projects (ADPs) in Nigeria, NGOs such as GLOBAL 2000, National Seed Services (NSS), the National Agricultural Extension and Research Liaison Office (NAERLS), Pioneer Hibred Seed Nigeria Ltd. Bulk quantities were provided to KNARDA, the University of Ibadan, Guiness Nigeria PLC and the Nigerian Breweries PLC for food and chemical tests. To share results on the performance of varieties (ICSV 111 and ICSV 400) and hybrids (ICSH 89002 and ICSH 89009), a workshop was organized on 9 March 1992 followed by another workshop to evaluate these and other promising elite cultivars from IAR.

Variety and hybrid testing continue in 1993 confirming the superiority of hybrids (ISCH 89009 NG, ISCH 89002 NG) and composites (ICSV 400 and ICSV 111). Seed from improved and advanced cultivars were supplied for on farm and on station trials to NCSRP, IAR, KNARDA and JARDA. To further promote improved varieties and hybrids, seed of improved cultivars were supplied to the NCSRP, KNARDA, JARDA, ADPs of Bauchi, Yobe, and Borno states, the national agricultural land development authority (NALDA), the North-East Arid Zone Development Programme (NAEZP) and other extension agencies. Grain quality testing was carried out by the NAERLS for the suitability for preparing local Nigerian dishes. In 1994 and 1995, the same varieties were found to be superior following multi-locational on-farm trials. In 1996, these varieties were officially released (ICRISAT 1993&1994).

From 1996 to 2002, ICRISAT through the technology exchange programme initiated a large promotion of improved sorghum cultivars in partnership with ADPs, NGOs, rural development projects and seed companies.

3.2. Pearl millet research and development

During the last 20 years, four pearl millet varieties were released in Nigeria since 1996. These include SOSAT C88, LCIC 9702, LCIC 9703 and GB 8735. These varieties were bred in other countries and adapted in Nigeria such SOSAT C88 which as bred in Niger and Mali and GB 8735 which was bred in Niger. SOSAT C 88 is a joint work between ICRISAT and the Institut d'Economie Rurale (IER), LCIC 9702 and LCIC 9703 are offshoot of GB8735. The variety GB 8735 was developed by ICRISAT.

From 1996 to 2002, ICRISAT launched a large promotion of these varieties in partnership with ADPs. The 4 varieties were tested through multi-locations to assess their adaptability. Thereafter, these varieties were formally released. This was followed by a large promotion of these varieties by Agricultural Development Projects (ADPs), NGOs, rural development projects and seed companies. Knowledge of technology exchange work that was carried out by ICRISAT is still limited (Gupta et al., 1999).

3.3 Profile of modern varieties investigated

3.3.1. Profile of sorghum varieties

Sorghum varieties released less than 25 years ago where the object of investigation. These include ICSV 111, ICSV 400, Sorghum hybrids and SK 5912. The profile of these varieties is described below.

ICSV-111

This is an early maturing sorghum variety (90-110 days). It was developed by ICRISAT India and introduced to Nigeria through IAR. It is of medium height (1.7-2.2 m), with yield potential of 3 tons/ha. It is tolerant to drought and major leaf diseases and has strong resistance to sorghum pests. The heads are semi-compact and thresh freely without any awns. The cultivar has high tillering ability that makes it possible to harvest it more than once. It was officially released in 1996, farmers had been exposed to it through OFAR trials since 1992 (Oloka, et al. 2000).

ICSV-400
It is an early maturing variety (105-110 days), with an average 2 m height with very good grain quality and resistant to lodging. This variety was developed by ICRISAT India and introduced in Nigeria through IAR. The maturity is between 100 and 120 days. It has excellent malting properties. Its shares similar characteristics as ICSV 111 and was released in 1996 by the National Crop Variety release Committee (NCVRC).

ICSH 89002 NG
This is a hybrid variety with about 69 days to flowering, 205 cm plant height, with grain yield averaging 5.97 ton/ha.

ISCH 89009 NG
This is a hybrid variety with about 67 days to flowering, 183 cm plant height, with grain yield averaging 5.84 ton/ha.

SK5912
The variety SK 5912 (also called SAMSORG 17, SSV3) was created in 1970. It is susceptible to *Striga*, head miner, less susceptible to mildew and smut.

3.3.2. Profile of modern pearl millet varieties investigated.

Pearl millet varieties released less than 25 years were considered in this study as modern varieties. These varieties include SOSAT C 88, LCIC 9702, LCIC 9703, GB 8735 and ZATIB.

SOSAT C88
This variety was developed by ICRISAT and IER and is a cross between **Souna** and **Sanio**. It is medium maturing variety (90 days), with an average height of 2 m, medium head length (28 cm on average) with compact head but sensitive to stem borers. The recommendation domain in terms of rainfall is the range of 350-600 mm annual rainfall on sandy and semi-clay soils. This variety is preferred for its food taste, earliness and high grain yield. SOSAT C88 was developed in 1988 and released by the NCVRC in Nigeria in 2000.

LCIC 9702 (LCICMV-2)
This variety was developed jointly by LCRI and ICRISAT (at then ICRISAT Kano Station) using recombined S1 of ICMV88908, RCB-IC911 &GB8735. It is early maturing variety (75 days), with an average height of 1.5m, medium head length (20cm on average) with compact head but sensitive to downy mildew disease under high humidity. The recommendation domain in terms of rainfall is the range of 300-600 mm annual rainfall on sandy and semi-loamy soils. This variety is preferred for its earliness (intervention variety before harvest of other pearl millet varieties), food taste, bold grain and moderate grain yield. It is an improved version of GB 8735 and yields 20% more. **LCIC 9702** was developed in 1997 and released by the NCVRC in Nigeria in 2003.

GB 8735
This variety was developed by ICRISAT and is a cross between the local cultivars **Iniadi** and **Souna**. It is an early maturing variety (80 days), with average height of 1.5 m and short head (22 cm on average). This variety is sensitive to stem borers. It is recommended in the 350-600 mm rainfall zone on sandy and semi-clay soils. GB8735 was developed in 1987 and released in Nigeria in ?????

ZATIB
This variety was developed by INRAN and is a cross between local cultivars **Zanfarwa** and **Tchin-Bijini**. It is medium maturing variety (95 days), with height between 190-200 cm, longer head length (65 cm on average) with compact head but sensitive to stem borers. The recommendation domain in terms of rainfall is the range of 550-800 mm annual rainfall on sandy and semi-clay soils. ZATIB was developed in ???? and released by the NCVRC in Nigeria in ????.

3.4. Review of literature on adoption of modern pearl millet and sorghum varieties in West Africa and especially Northern Nigeria

A diagnosis survey carried out in the North-East zone of Nigeria showed that the major constraints to cereal production are gender reflecting the marginalization of women, marital status, educational and belief. Economic constraints were identified as insufficient labor due to rural-urban drift, low access to capital and unstable government policies. Technical constraints are the low access to information on technologies and innovations by farmers, and seed of modern sorghum and pearl millet varieties (Anogie, D.A. et al. 2009). This is consistent with other existing studies on technology adoption in Africa that found limited access to credit and inputs supplies, post-harvest processing problems, output markets constraints, etc., as important determinants for adoption of new varieties (Adesina and Zinnah 1993; Adesina and Seidi 1995; Adesina and Baidu-Forson 1995; Feder et al. 1985; Yapi et al. 1998, 1999a&b, 2000; Ndjeunga and Bantilan, 2005).

Few studies have been carried out on adoption and impact of sorghum and pearl millet research and development interventions in Northern Nigeria. Factors affecting adoption of ICSV 111 and ICSV 400 were identified by Ogungbile et al 2002. Using a sample of 219 farmers from 27 villages, drivers of adoption were identified as farming experience, household size, farm size and usage of sorghum grain though not consistent by state. Technology traits explaining adoption were early maturity and yield. Low adoption of the 2 sorghum varieties was limited due to poor promotion of these technologies by extension services. According to farmers, ease of threshing was also said to have led to a reduction of total labor requirements in the production of these varieties. The short stalk of these varieties was not particularly preferred but its good palatable fodder was highly preferred. Farmers complained of low yield performance of the improved varieties especially when fertilizer is not applied.

Macaver (2002) assessed the economic impact of public investments in sorghum research and extension in Katsina State, Nigeria. A sample of 240 farmers was selected randomly. The rate of adoption measured as the proportion of sorghum land planted to the improved cultivars ranged from 12% in 1982 to a peak of 27% in 1996, thereafter dropped to 25% in 1997 and 1998 further down in to 24% in 1999 and 2000. Factors affecting adoption of improved cultivars (ICSV111, ICSV400, SAMSORG-3 and SAMSORG-9) were identified as the age of the farmer, cultivar maturity time, disease resistance, food quality, extension contacts, and level of formal education.

Unreliability of seed and fertilizer availability were also found as constraints to uptake of improved cultivars. The four improved cultivars had a 40% yield advantage over the local variety (*Yaruruka*) while the average net income advantage was 142%.

Using an economic surplus model, the internal rate of return to investment in the sorghum R&D was estimated to 62% yielding a NPV of 17 million Naira. However, consumers captured 188% of the project social gains while producers realized -88% (Macaver, 2002). The study recommended that more tax payers' money be invested in sorghum R&D since producers cannot bear the costs of research because of the negative producers' surplus. Some level of fertilizer subsidy should be maintained by taxing industries using grains of sorghum R&D. To achieve project sustainability, efforts should be made to develop new markets for sorghum to avoid future price collapse, attract research funding from nontraditional sources and commercialize findings of the sorghum R&D.

IV - Methodology and data

4.1 - Sample selection

A survey of 119 villages and 1105 households in 6 states of Northern Nigeria was carried out from December 2009 to January 2010 (Figure 1). The selected states account for about 47% of pearl millet area cultivated and 49% of pearl millet production in Nigeria. These states account for about 50.30% of sorghum area cultivated and 48.85% sorghum production in Nigeria. The number of villages selected per state was proportional to state population size based on the 2006 population census (CountrySTAT, 2010). Thus, 19 villages were selected in Borno State, 12 in Yobe, 23 villages in Katsina, 29 villages in Kano, 20 villages in Jigawa and 16 villages in Zamfara state. Within village, 10 households were randomly selected based on a census list provided by the chief of village. Table 2 below presents the distribution of households producing pearl millet and sorghum by state.

Table 2. Distribution of households by state in Northern Nigeria

	Surveyed States						
Type of producer / type of village	Borno	Jigawa	Kano	Katsina	Yobe	Zamfara	Total
Pearl millet producers							
Non-project village	16	89	26	110	85	67	393
Project village	98	89	226	93	30	118	654
Sub-Total	*114*	*178*	*252*	*203*	*115*	*185*	*1,047*
Sorghum producers							
Non-project village	19	87	29	127	88	64	414
Project village	120	81	230	88	29	119	667
Sub-Total	*139*	*168*	*259*	*215*	*117*	*183*	*1081*

Source : Impacts of Sorghum and Pearl Millet Varieties in Northern Nigeria survey, 2008-10

Since households are both sorghum and pearl millet producers, a total of 1105 households were interviewed on both pearl millet and sorghum. Overall, 994 households were pearl millet producers, 998 households as sorghum producers and XXX as both pearl millet and sorghum producers. Data were collected at village, household and plot levels. Village information included village profile, access to roads, markets and services, village population where necessary, village land occupation and relative importance of crops, land tenure systems, projects and programs that have been implemented in the village, prices of input and product markets, and factors of production, livestock prices, wages, credit sources, and units of measurements.

At household level, data were gathered on household socio-demographic and economic profile, land stocks and agricultural equipment, diffusion mechanism of sorghum and pearl millet varieties, varieties grown during the last 5 years, participation in technology transfer activities, social capital, crop production and stocks, livestock production and stocks, assets owned, sources and access to credit, crop and livestock transactions and household perception of welfare changes. Plot information included plot characteristics, use of inputs (seed, organic and inorganic fertilizers), sources of seed, organic and inorganic fertilizers, period of application, quantities applied, farmers' perception of fertility level, production level, and finally farmers' perception of welfare changes.

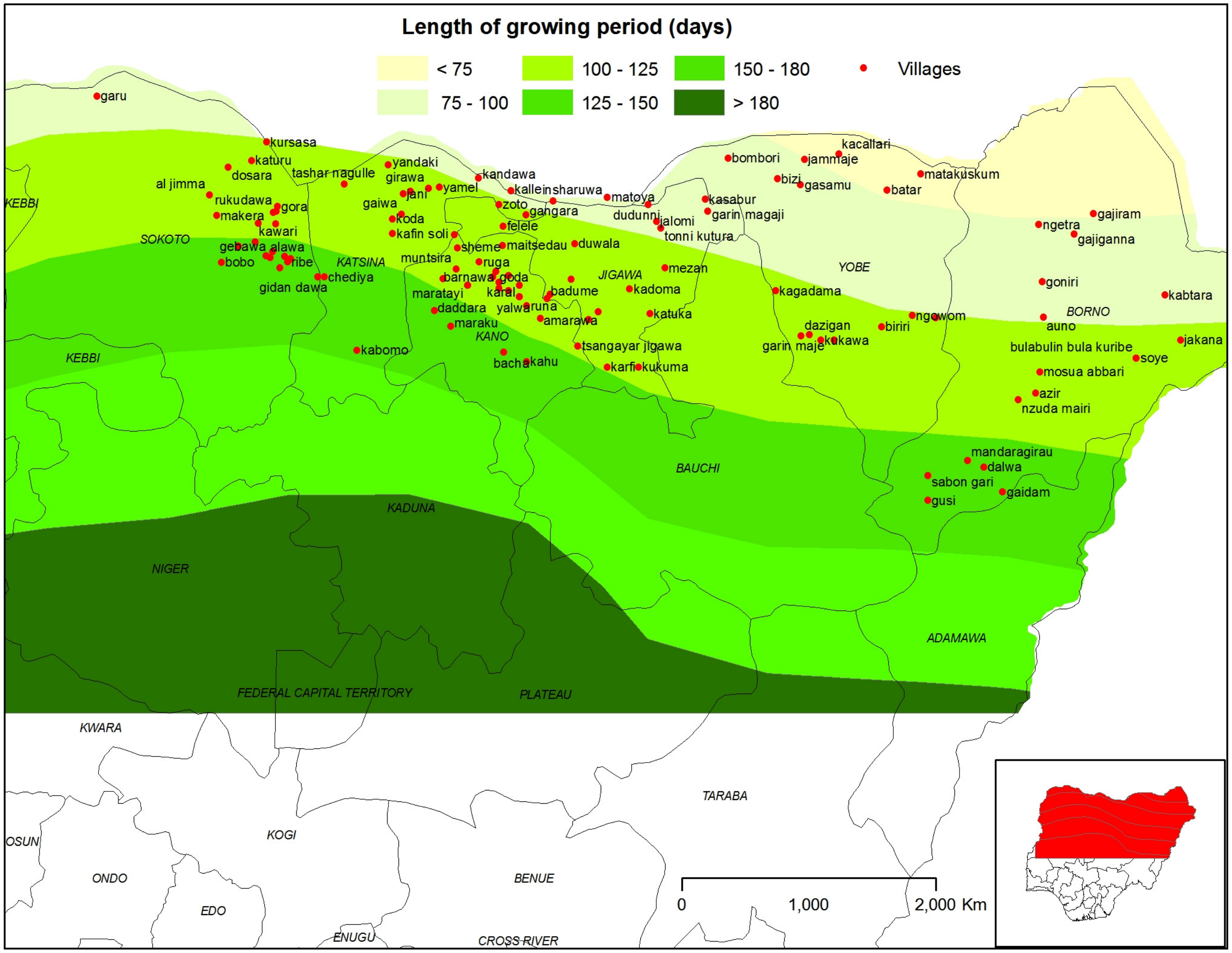


Figure 5. Selected surveyed villages in 6 states of Northern Nigeria

4.2 Data analysis

Analysis of the data included the use of simple descriptive statistics, matching methods, multivariate econometric methods, and methods of economic cost benefit analysis to estimate the impacts and the discounted gross benefits of investments. We discuss each of these methods briefly.

4.2.1 Descriptive statistics

The descriptive statistics reported usually include the mean and standard deviation, as well as the median of variables in many cases where outliers are a concern. For categorical variables, such as the level of education of the household head, we report percentage of sample households, villages or plots under each category. We report and compare all explanatory, response and outcome variables used in the analysis.

4.2.2 Matching methods

The basic problem in assessing the impact of a technology on the participants is that the counterfactual situation – what would have happened to the participants had they not participated – is not observed. For example, if a project's outcome indicator is household income, the average impact of a technology on the beneficiaries (referred to as the average effect of the treatment on treated (*ATT*) is defined as the difference between the expected income earned by technology beneficiaries while participating in the project and the expected income they would have received if they had not participated in the project:

Where p = participation in the project (*p=1* if participated in the project and *p=0* if did not participate in the project); Y_1= outcome (household income in this example) of the project beneficiary after participation in project; Y_0 = outcome of the same beneficiary if he/she had not participated in the project; and *E()* refers to expected value.

$$ATT = E(Y_1|p = 1) - E(Y_0|p = 1)$$

Unfortunately, we cannot observe the counterfactual income of the beneficiaries had they not participated in the project $E(Y_0|P=1)$. Simply comparing incomes of households that are participating in the project and those that aren't can result in serious biases, since these two groups may be quite different and hence likely to have different incomes regardless of their participation in the project. For example, adding and subtracting $E(Y_0|P=0)$ on the right hand side of equation (1), we have:

$$ATT = [(E(Y_1|p = 1) - E(Y_0|p = 0)) - (E(Y_0|p = 1) - E(Y_0|p = 0)]$$

The first expression (in the first square bracket) in equation (2) is observable since it is the simple difference of mean income between the beneficiaries and non-beneficiaries. The second expression (which is unobservable because $E(Y_0|P=1)$ is unobservable) represents the bias resulting from estimating *ATT* using the first expression. This bias results because the income or outcome that non-beneficiaries receive without the pearl millet or sorghum research and development program may not be equal to the income that beneficiaries would have received without the program. Two common sources of bias are program placement or targeting bias, in which the location or target population of the program is not random (e.g., if poorer regions or households are targeted by the program); and self-selection bias, in which households choose whether or not to participate, and thus may be different in their experiences, endowments and abilities.

The most accepted method to address these problems is to use an experimental approach to construct an estimate of the counterfactual situation by randomly assigning households to treatment (beneficiary) and control (non-beneficiary) groups. Random assignment assures that both groups are statistically similar in both observable and unobservable characteristics, thus avoiding program placement and self-selection biases. Such an approach is not feasible in the present study since program placement and participation decisions were already made prior to design of this study, and are unlikely to have been random. The notion of random assignment also conflicts with the nature of community-driven development programs, in which communities and households make their own decisions about whether to participate and what activities they will pursue; thus limiting the ability to use this approach even from the outset.

Various quasi-experimental and non-experimental methods have been used to address the attribution problem (Rosenbaum and Rubin, 1983; Heckman, et al., 1998; Ravallion 2005). One of the most commonly used quasi-experimental methods used is propensity score matching (PSM), which selects project beneficiaries and non-beneficiaries who are as similar as possible in terms of observable characteristics expected to affect sorghum and pearl millet research and development program participation as well as outcomes. The difference in mean outcomes between the two matched groups can be interpreted as the *ATT*; i.e., the impact of the project on the beneficiaries.

A key assumption necessary for matching estimators to consistently estimate the impacts of a treatment on the treated is that the outcome that would occur without the program is independent of whether or not the household is in the program, conditional on observed characteristics of households (conditional independence assumption) (Rosenbaum and Rubin, 1983). This assumption assures that the expected value of the outcome variable for the non-participant group is equal to the expected value of what the outcome of the participant group would have been, had it not participated (i.e., that $E(Y_0|p=1)=E(Y_0|p=0)$).

Matching can be done on individual covariates, but if there is more than one continuously distributed covariate, some type of distance metric is needed to aggregate differences between observations of multiple variables into a scalar measure to identify closely matching observations. PSM uses a particular distance metric – the propensity score – which is measured by estimating the probability of being in the program (usually using a probit or logit model) as a function of observed covariates that jointly affect the probability of participation and the impact of the program. In measuring the "distance" between participant and non-participant households, PSM implicitly gives greater weight to covariates that have a greater impact on the probability of program participation. This is useful, since the variables that have a stronger influence on participation are the ones that have more potential to bias the estimated impact if not adequately matched.

There are several ways to select the matching observations using propensity scores, including selecting the nearest neighbor (i.e., select for each treated observation the matching non-treated observation with the closest propensity score), the nearest N neighbors, all neighbors within a certain radius (radius matching), or calculating a matching observation based on a weighted mean of its neighbors, with the weights declining as the distance increases (kernel matching). The choice of method involves tradeoffs between bias and efficiency, with nearest neighbor matching minimizing bias, since it uses the best available match, but having lower efficiency than other methods because it discards information about other near matches. An additional issue is estimation of correct standard errors. Since the propensity scores are based on estimated coefficients rather than the true coefficients, this first stage estimation causes additional errors that are not accounted for by standard calculations. A common practice is to use bootstrapping to estimate standard errors, but it has been shown in a recent paper (Abadie and Imbens, 2006) that for nearest N neighbor matching, this does not estimate correct standard errors. Considering this problem, and the greater efficiency of kernel over nearest neighbor matching, we decided to use kernel matching but will report the NN matching as well.

In the matching procedure, we dropped observations that do not have “common support”; meaning observations that are not within the ranges of values of the covariates for which both participant and non-participant groups are represented. This resulted in dropping relatively few observations. Requiring common support reduces a potential bias that can exist in regression models resulting from comparing observations that are from completely different regions of the space of covariates (e.g., if the wealthiest program participants are wealthier than any non-participants or the poorest non-participants are poorer than any participants, including those participants can bias the results of regression models). This helps to avoid biases from comparing non-comparable observations.

The results of the PSM may be biased as a result of imperfect matches. We tested for statistical differences in the covariates between the participants and non-participants in the unmatched and matched samples and found statistically insignificant differences in the matched samples for almost all covariates, though there were many significant differences in the unmatched samples. We also found that the mean levels of the covariates were more similar in almost all cases in the matched samples than the unmatched samples. These results indicate that PSM has reduced potential biases, but it may not have eliminated them, since some differences remain in the matched samples.

To address possible bias in the PSM results, we also used the bias corrected N nearest neighbor matching estimator developed by Abadie et al. (2004). This estimator has the advantages that it corrects for the bias using auxiliary regressions and estimates the analytically correct standard error for the ATT. Unfortunately; the distance metric used by this estimator is more arbitrary than the PSM metric. The distance metric used by this procedure is based on the sum of the magnitudes of differences in values of the covariates, weighted by the inverse of the standard errors of these variables. Unlike the PSM metric, this metric does not account for which covariates have a greater impact on the probability of program participation. Given that each matching estimator has disadvantages as well as advantages, we decided to use and report the results of both estimators.

The covariates that we used in the matching estimations for impacts on the household response and outcome variables (e.g., average household crop yield, per capita crop production per hectare) include variables reflecting the household’s endowments of natural, physical, human and social capital, and the quality and tenure of the plot. These were:

- Amount of land owned (in ha) in 1999
- Average quality of the soil of plots used by households (soil fertility, soil texture)
- Tenure of the plot (family vs. individual plot, means of plot acquisition)

- Value of livestock owned in 1999
- Value of farm equipment owned in 1999
- Value of household assets (transportation equipment, other durable goods) owned in 1999
- Age and education of the household head in 1999
- Dependency ratio in 1999

The models also included state fixed effects (different intercepts for each state), which account for all state level factors affecting adoption (e.g., agro-ecological zone, access to markets and infrastructure, etc.). In the matching estimations for gross income per capita we used the same explanatory variables, except that we used household level aggregate versions of the plot variables (e.g., share of land of particular qualities or tenure).

We used the values of endowments and other time-varying covariates in 1999, rather than in 2009/10, as determinants of the propensity scores, because of concern about reverse causality. Endowments may be affected by participation in programs as well as affecting participation. By using earlier levels of endowments, these levels are less likely to have been affected by program participation. There still may be problems of reverse causality for older programs, but we are unable to do more to address this problem with our data. Interpretation of the coefficients of the propensity score regression may be affected by this reverse causality. Fortunately the validity of the results of PSM does not depend upon the exogeneity of the covariates used to predict the propensity scores, as long as the conditional independence assumption is satisfied (Heckman et al. 1988).

Matching methods have some advantages over econometric regression methods since they compare only comparable observations and rely less on parametric assumptions to identify the impacts of projects (Heckman et al. 1988). However, matching is subject to the problem of "selection on unobservables", meaning that the beneficiary and comparison groups may differ in unobservable characteristics, even though they are matched in terms of observable characteristics. This could lead to violation of the conditional independence assumption underlying matching. Econometric instrumental variables regression methods have been devised to address this problem, although these suffer from the problems noted above. We used econometric methods to address these concerns and check robustness of the conclusions from the matching methods. These methods are described further below.

4.2.3 - Econometric analysis

We use econometric models to estimate the impacts and other factors on use of sorghum and pearl millet varieties, on the gross value of crop production at household level, and on gross household income per capita. The explanatory variables included in these regression models included the adoption of improved pearl millet and/or sorghum varieties, plus the same covariates used to estimate propensity scores in the PSM model. The only difference is that 2009/10 values of household endowments and other time varying covariates were used in the per capita total value crop production and per capita gross revenues regressions, rather than 1999 values, as in the PSM model. The reason for this is that the concern about reverse causality does not apply in these regressions, since the endowments were measured as of the beginning of the current crop and income year, so would not be affected by crop production and gross revenues in 2009/10. As in the PSM model, we used household level aggregates of the plot level covariates in the model for household income per capita.

The type of econometric model used was different for adoption of varieties, since these are binary (yes/no) response variables, than for per capita total value of crop production and gross revenue per capita, which are continuous variables. To estimate the determinants of adoption, we used binary probit models. To estimate the determinants of per capita value of crop production and gross revenue, we used least squares regression models. In the per capita value of crop production and per capita gross revenue models, we transformed the dependent variables using the natural logarithmic transformation (i.e., we estimated determinants of ln(per capita gross value of crop production) and ln(per capita gross revenue)). Using the logarithmic transformation reduces problems of outliers and heteroskedasticity (Mukherjee et al. 1998).

As mentioned above, instrumental variables methods are available to deal with problems of selection on unobservables. We use instrumental variables (IV) (also known as two-stage least squares) regressions to test whether there are such problems in the econometric models. The instrumental variables we used for adoption of varieties are the predicted probabilities of awareness on varieties from the probit models used in the PSM. Tests of the relevance of these instrumental variables in the IV versions of the models determining adoption of varieties and ln(per capita value of crop production) found that these instruments are strong predictors of awareness, and that under-identification of the IV model is rejected (Davidson and MacKinnon 2004). A "C-test" was used to test the exogeneity of the program participation variables (Baum, et al. 2002), and was found to support in almost all exogeneity of these variables, meaning that concerns about selection on unobservables are statistically rejected. Hence, the probit models (in the case of adoption of varieties) and ordinary least squares model (in the case of per capita value of crop production) is preferred, as they are more efficient than the IV model. This also helps to support the conditional independence assumption of the matching estimators.

As mentioned above, we estimated the outcome models (per capita value of crop production, etc..) including adoption of varieties as explanatory variable, to be able to assess the direct impacts of varieties on productivity, controlling for other factors. We also estimated a reduced form version of the model without adoption included; in this case the total impacts of participation in programs, considering the effects of programs on adoption of varieties, are estimated. We first estimated an unrestricted ordinary least squares (OLS) version of the regression, including all of the explanatory variables mentioned above, plus the adoption of varieties. Then we used a Wald test to test the joint statistical significance of several household level variables that were hypothesized to affect production only by adoption of varieties. These variables were found to be jointly statistically insignificant and were removed from the model to improve model efficiency and identification in an IV version of the restricted model. Restricted OLS and IV models were estimated, excluding the jointly insignificant household level variables and using them as instrumental variables, which may be subject to endogeneity bias, in the IV model. Other instrumental variables used in the IV model included the value of endowments and other time-varying covariates as of 1999. A Hansen's "J" overidentification test was conducted to test the validity of the instruments used, and the test supported their validity (Davidson and MacKinnon 2004). The strength of identification of the IV model was tested using Anderson's canonical correlation likelihood ratio statistic, and weak identification was found to be a problem, suggesting that the results of the IV model could be seriously biased (Bound et al. 1995). The C test for exogeneity of adoption of varieties failed to reject exogeneity of varieties, so the restricted OLS model is preferred to the IV model.

For per capita gross revenues or total value of crop production, we estimated 3 regressions: an unrestricted OLS model, including all of the explanatory variables, a restricted OLS model in which the household head's social status variables were dropped (these were found to be jointly statistically insignificant in the unrestricted model), and an IV version of the restricted model. The social status variables and the household's endowments in 1999 were used as instrumental variables for the adoption variables in the IV model. Identification tests supported the validity of the instrumental variables used, but showed that weak identification of the model is a problem. The C test failed to reject exogeneity of the program participation variables, so the restricted OLS model is preferred.

4.2.4. Stochastic dominance analysis

Using the matched samples, we plotted the cumulative density functions (cdf) of the average household yield, per capita total value of production, per capita total wealth of households and per capita total sale of sorghum or pearl millet for adopters and non-adopters of at least one modern pearl millet or sorghum variety. This allowed us to investigate the impacts of adoption of modern varieties on the entire distribution of yield, total value of crop production per household, and not only on the mean value. In comparing these cdf's we assess whether the distribution with adopters (first order) stochastically dominates the distribution without adoption, which means that the probability of average household yield, per capita wealth and per capita value of sales falling below any threshold level is lower with the practice than without it (Mas-Colell, et al. 1995). When this occurs, adoption of modern varieties reduces risk as well as increasing mean yield. Simple comparison of cdf's using unmatched samples could lead to biased conclusions, since other factors besides adoption in question could be responsible for differences in the distributions. We use the matched samples for this in order to reduce this potential bias.

V - Results and discussions

This section presents the socio-demographic profile of sorghum and pearl millet producers, livelihood assets owned by the households, factors explaining exposure to modern pearl millet and sorghum varieties, determinants of adoption of modern varieties, and impacts of sorghum and pearl millet on household livelihoods.

5.1. Socio-demographic profile of sorghum and pearl millet producers

Adoption of technologies and innovations has been largely explained through literature as being a function of household socio-demographic profile as well described by the seminal review of Feder et al (1985). It can be explained by household socio-demographic profile such as age, formal education, household size, total work force and marital status. Table 3 presents some socio-demographic characteristics of the surveyed farmers. All pearl millet producers' head of households are male and almost all of them are married. However, it can be noted that in Yobe State about 12% of household heads are female. The average age of pearl millet farmers is estimated to about 50 years with no significant differences between states. Household size is estimated to 9 members and almost 73% of farmers are illiterate. More than half the producers are received koranic education. The total workforce is estimated to about 2 adult-equivalents. The same results are recorded for sorghum farmers.

Table 3. Socio-demographic profile of the sample by surveyed States in Northern Nigeria

	State							
Variable	**Borno**	**jigawa**	**kano**	**katsina**	**yobe**	**zamfara**	**Total**	
Pearl millet producers	***(114)***	***(178)***	***(252)***	***(203)***	***(115)***	***(185)***	***(1047)***	**Fisher (F) / CHI2**
Age of household head (years)	53.10	49.70	49.91	53.35	47.44	50.30	50.69	5.79***

Percent of male (%)	100.00	100.00	99.60	100.00	87.83	100.00	98.57	105.75***
Household size	9.28	9.02	10.81	9.53	10.53	10.66	10.03	3.88***
Adult equivalent	2.58	1.96	2.19	2.37	2.49	2.07	2.24	20.47***
Dependency ratio	1.01	1.41	1.09	1.40	1.78	1.46	1.34	6.27***
Marital status (living with spouse) (%)	99.12	98.88	99.21	99.51	88.70	99.46	98.09	61.10***
Illiteracy (%)	78.07	61.24	79.37	69.95	73.04	78.92	73.54	23.55***
Adult numeracy/literacy (%)	14.29	6.90	2.81	3.47	3.51	14.92	7.07	38.89***
Koranic education (%)	44.64	44.83	71.08	61.88	41.23	56.91	56.20	50.69***
Sorghum producers	**(139)**	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**	**Fisher (F) / CHI2**
Age of household head (years)	51.33	49.63	49.84	53.43	47.61	50.42	50.57	4.89***
Percent of male (%)	100.00	100.00	100.00	99.53	87.18	100.00	98.52	115.95***
Household size	8.92	8.92	10.52	9.42	10.49	10.91	9.91	4.82***
Adult equivalent	2.35	1.97	2.17	2.39	2.47	2.07	2.22	14.40***
Dependency ratio	1.00	1.40	1.08	1.43	1.78	1.43	1.32	7.09***
Marital status (living with spouse) (%)	98.56	98.81	99.23	99.53	88.03	99.45	97.96	65.48***
Illiteracy (%)	71.94	60.71	79.54	70.23	72.65	77.60	72.71	21.17***
Adult numeracy/literacy (%)	10.79	6.10	2.72	3.27	3.45	15.73	6.65	39.80***
Koranic education (%)	42.45	45.73	71.98	61.21	40.52	55.06	55.71	57.62***

Sample size in parentheses

**Significant at 10%, **Significant at 5% and ***Significant at 1%*

Source : Impacts of Sorghum and Pearl Millet Varieties in Northern Nigeria survey, 2008-10

5.2. Livelihood assets owned by households

Likewise, socio-economic factors such as farm size, tenurial status, level of income, credit access and price stability do influence adoption of innovations. Infrastructural and institutional factors such as access to roads and information communication technologies (ICT), input supply and distribution services, and extension services explain adoption as well. Pearl millet farmers owned on average 3.33 ha of which 2.96 ha is cultivated. The area planted with pearl millet is estimated to 0.97 ha and that of sorghum 0.92 ha. The value of agricultural equipment owned by households is estimated to 74850 Naira (US$ 535 with US$1=140 Naira) and the value of animal traction to 174655 Naira (US$1,248). The value of durable assets is estimated to about 232,960 Naira (US$ 1664 with US$1=140 Naira). Similar trend is recorded for sorghum producers.

Table 4. Livelihood assets owned by sampled households by surveyed State in Northern Nigeria

				State				
Variables	**borno**	**jigawa**	**kano**	**katsina**	**yobe**	**zamfara**	**Total**	
Pearl millet producers	*(114)*	*(178)*	*(252)*	*(203)*	*(115)*	*(185)*	*(1047)*	**Fisher (F)**
Land owned per capita	0.90	1.21	0.47	0.63	0.60	0.85	0.76	17.94***
Land cultivated per capita	0.55	0.94	0.37	0.51	0.52	0.78	0.60	16.21***
Area millet per capita (ha)	0.21	0.32	0.08	0.18	0.38	0.26	0.22	10.32***
Area sorghum per capita (ha)	0.21	0.26	0.10	0.18	0.47	0.25	0.22	11.78***
Value of equipment (USD)	215.72	1105.32	526.94	820.27	4665.81	1451.33	1266.2	6.62***
Value of animal traction (USD)	42.29	614.89	202.81	606.54	1847.89	1130.27	678.24	2.98**
Sorghum producers	**(139)**	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**	**Fisher (F)**
Land owned per capita	0.95	1.22	0.48	0.63	0.63	0.85	0.76	17.92***
Land cultivated per capita	0.58	0.98	0.38	0.51	0.58	0.77	0.61	15.87***
Area millet per capita	0.14	0.28	0.08	0.15	0.37	0.25	0.19	14.49***
Area sorghum per capita	0.25	0.26	0.11	0.17	0.48	0.25	0.23	11.59***
Value of equipment (USD)	232	1136	510	812	4605	1496	1242	6.87***
Value of animal traction (USD)	53	662	195	622	1828	1174	677	3.21***

Sample size in parentheses

*Significant at 10%, **Significant at 5% and ***Significant at 1%
Source : Impacts of Sorghum and Pearl Millet Varieties in Northern Nigeria survey, 2008-10

It is estimated that about 50% of the pearl millet producers use bicycle, 42% motorcycles, and very few 3% vehicles as a major means of transport (Table 3). On average 37% of pearl millet producers own a cell phone, 80% own a radio and 10% own a television. Similar results are recorded for sorghum producers. Awareness is a critical factor for adoption of innovations and technologies. The use of radios is credible tool to disseminate technological or market information critical for farmers to increase productivity and ease access to markets.

Table 5 . Proportion (%) of households owning at least one of the assets in 2008-09

				State				
Variables	**borno**	**jigawa**	**kano**	**katsina**	**yobe**	**zamfara**	**Total**	
Pearl millet producers	***(114)***	***(178)***	***(252)***	***(203)***	***(115)***	***(185)***	***(1047)***	**CHI2**
Bicycle	40.35	35.96	55.95	47.29	40.00	57.30	47.66	28.76***
Cellular	31.58	38.20	41.27	29.06	26.96	35.68	34.77	12.20***
Motorcycle	30.70	27.53	43.65	34.98	44.35	52.97	39.54	33.09***
Radio	84.21	71.35	76.98	70.94	73.04	86.49	76.89	21.10***
Residence stone	30.70	16.29	14.29	3.45	1.74	8.65	11.94	69.90***
Residence mud with tin rood	48.25	47.19	61.51	43.35	48.70	55.14	51.58	18.65***
Residence mud without tin rood	28.07	28.09	17.86	35.47	40.87	20.54	27.13	33.28***
Telephone apparatus	3.51	0.56	1.98	4.93	5.22	2.70	2.96	9.33*
Television	19.30	2.25	9.13	18.23	0.87	14.05	10.79	48.25***
Vehicle	3.51	2.81	2.38	2.96	1.74	5.41	3.15	4.46
Sorghum producers	**(139)**	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**	**CHI2**
Bicycle	45.32	36.31	57.53	48.84	38.46	59.02	49.12	31.65***
Cellular	27.34	39.88	40.54	28.37	26.50	38.25	34.41	17.53***
Motorcycle	30.22	29.76	41.70	37.21	44.44	54.10	39.87	30.03***
Radio	82.73	70.83	76.45	72.09	73.50	87.43	77.06	21.24***
Residence stone	21.58	16.67	14.67	4.65	2.56	8.74	11.56	41.10***
Residence mud with tin rood	48.92	47.62	60.62	44.65	51.28	56.83	52.27	15.88***
Residence mud without tin rood	27.34	29.17	17.76	33.02	38.46	21.31	26.64	26.53***
Telephone apparatus	1.44	0.60	1.54	4.65	5.13	3.28	2.68	11.03*
Television	16.55	1.79	9.27	18.14	0.85	15.85	11.01	47.58***
Vehicle	2.88	2.38	1.54	2.79	1.71	6.01	2.87	8.83

Sample size in parentheses
*Significant at 10%, **Significant at 5% and ***Significant at 1%
Source : Impacts of Sorghum and Pearl Millet Varieties in Northern Nigeria survey, 2008-10

Table 6. Outcome variables generated by the adoption of modern pearl millet varieties.

				State				
	Borno	**Jigawa**	**Kano**	**Katsina**	**Yobe**	**Zamfara**	**Total**	
Outcome Variable	**(114)**	**(178)**	**(252)**	**(203)**	**(115)**	**(185)**	**(1047)**	**Fisher (F)**
Total value of crop production	1756	1236	1812	1340	1842	3115	1850	19.70***
Total value of livestock owned	1530	2633	3636	2425	2384	3606	2859	2.11*
Total of farm revenue	534	203	622	706	153	536	491	1.45
Total revenue of household	3820	4071	6070	4471	4379	7256	5199	5.04***
Total value of crop product sales	1790	86	705	204	393	438	539	19.38***
Total value of durable	2079	1130	1740	1299	1295	1465	1490	21.2***
Household total wealth	4492	8793	7286	7798	7610	11256	8074	7.01***

Household total expenditure	529	1749	1641	2718	3282	3406	2239	8.49***
Total value of crop product per capita	228	166	231	149	201	334	219	11.00***
Total value of livestock per capita	132	364	421	292	235	388	328	1.65
Total of farm revenue per capita	79	24	47	89	18	60	54	2.20*
Total revenue of household per capita	438	553	699	531	454	781	601	2.43**
Total value of crop sales per capita	179	7	77	25	37	52	57	17.53***
Total value of durable per capita	259	168	210	174	146	185	190	7.19***
Household total wealth per capita	485	1266	843	948	728	1226	951	6.54***
Household total expenditure per capita	119	242	225	332	402	365	281	3.78**

**Significant at 10%, **Significant at 5%, ***Significant at 1%*
Total revenue of household = TVP +livestock value + off farm revenue
Sample size in parentheses
**Significant at 10%, **Significant at 5% and ***Significant at 1%*
Household total wealth = Livestock value+ agricultural equipment value +durable assets value
Source : Impacts of Sorghum and Pearl Millet Varieties in Northern Nigeria survey, 2008-10

Table 7. Major variety dissemination projects

	State							
Variables	**borno**	**jigawa**	**kano**	**katsina**	**yobe**	**zamfara**	**Total**	**Chi2(5)**
Sorghum producers	**(139)**	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**	
Variety testing project	0.88	3.93	25.40	0.00	3.48	39.46	14.23	198.90***
Management training plots	1.75	17.98	6.35	9.36	5.22	5.95	8.21	32.96***
Seed production	0.00	2.25	33.73	0.00	0.00	9.19	10.12	215.30***
Crop production	0.00	4.49	0.00	4.93	0.87	0.00	1.81	28.96***
NPFS	47.37	71.35	34.52	75.37	80.87	43.24	56.73	139.93***
IFAD	27.19	0.00	0.00	5.91	4.35	0.00	4.58	163.59***
Fadama	52.63	0.00	0.00	5.91	10.43	2.70	8.50	335.69***
Sorghum producers	**(139)**	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**	
Variety testing project	0.72	4.17	23.94	0.00	3.42	40.44	13.69	211.04***
Management training plots	0.72	14.29	6.18	8.84	5.13	7.10	7.31	3.04***
Seed production	0.00	2.38	33.20	0.00	0.00	9.29	9.90	220.20***
Crop production	0.00	4.76	0.00	4.19	1.71	0.00	1.76	26.52***
NPFS	37.41	74.40	36.68	78.14	81.20	42.62	56.71	168.42***
IFAD	18.71	0.00	0.00	5.12	3.42	0.00	3.79	109.83***
Fadama	63.31	0.00	0.00	4.65	9.40	1.64	10.36	491.60***

Sample size in parentheses
**Significant at 10%, **Significant at 5% and ***Significant at 1%*
Source: Impacts of Sorghum and Pearl Millet Varieties in Northern Nigeria survey, 2008-10

Table 8. Outcome variables generated by the adoption of modern sorghum varieties.

	State							
Outcome Variables	**borno**	**jigawa**	**kano**	**katsina**	**yobe**	**zamfara**	**Total**	**Fisher (F)**
	(139)	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**	
Total value of crop product (USD)	1542	1259	1721	1358	1885	3178	1819	20.86***
Total value of livestock (USD)	1173	2549	3512	2302	2454	3756	2748	3.05***
Total of farm revenue (USD)	390	213	593	636	151	527	457	1.22
Total revenue of household (USD)	3105	4021	5826	4296	4489	7461	5023	6.72***
Total value of crop product sales (USD)	1418	92	684	194	400	444	517	13.79***
Total value of durable (USD)	1832	1146	1700	1300	1314	1485	1473	13.97***
Household total wealth (USD)	3776	8661	7061	7652	7744	11579	7844	10.16***
Household total expenditure (USD)	597	1753	1547	2387	3326	3469	2142	11.49***
Total value of crop product (USD) per capita	201	170	217	151	206	336	214	11.00***

Total value of livestock (USD) per capita	121	361	410	283	240	402	320	1.96*
Total of farm revenue (USD) per capita	55	26	46	80	17	59	50	1.56
Total revenue of household (USD) per capita	377	557	674	514	463	798	584	3.10***
Total value of crop product sales (USD) per capita	139	8	72	24	37	52	54	12.35***
Total value of durable (USD) per capita	257	174	209	175	148	186	193	6.52***
Household total wealth (USD) per capita	473	1273	829	940	744	1249	936	7.51***
Household total expenditure (USD) per capita	120	245	212	290	406	366	268	4.95***

Total revenue of household = TVP +value of livestock value + off- farm revenue
Household total wealth = Livestock value + Value of agricultural equipment +Value of durable assets
Sample size in parentheses
**Significant at 10%, **Significant at 5% and ***Significant at 1%*
Source : Impacts of Sorghum and Pearl Millet Varieties in Northern Nigeria survey, 2008-10

5.3. Farmers' preferences for traits of pearl millet and sorghum varieties under investigation

Simple probit regressions were used to assess the characteristics sought by farmers on the most popular pearl millet and sorghum varieties in Northern Nigeria. Results indicate that for the pearl millet variety SOSAT C88, farmers preferred its early maturing trait (+), its tolerance to insects (+), large grain size (+), grain color (+), good cooking time, but disliked for lower fodder yield (-), low storability (-), shorter head size (-). Through not significant, grain yield (+), grain color, cooking time, high head filling and easy to process may be positively valued by producers (Table 5).

As for the pearl millet variety GB 8735, farmers preferred it early maturing trait and good head filling but dislike its lower tolerance to insect pests. The variety ex-Borno released for than 20 years ago is till preferred by farmers for many positive traits such as higher insect tolerance, early maturity, higher fodder yield, larger grain size and good taste. Ex-Borno is disliked for lower marketability, shorter stalk and relatively difficult to process. The variety Zango is preferred for its long head and large stalk but is disliked for its longer maturity, and relatively longer cooking time.

For local varieties in general, farmers preferred the long head and large stalk but disliked its late maturity, lower insect tolerance, lower grain yield, smaller grain size, grain color, longer cooking time and poor head filling.

Table 9. Probit results on pearl millet variety characteristics preferred by producers

	SOSATC-88		GB 8735		Ex-Borno		Zango		Local varieties	
	coef	Se	coef	se	coef	se	coef	se	coef	se
Drought resistance (-1=Bad, 0=Average, 1=Good)	0.009	0.103	0.126	0.189	0.138	0.141	0.050	0.082	-0.118	0.083
Insect tolerance(-1=Bad, 0=Average, 1=Good)	0.370***	0.092	-0.410**	0.162	0.226*	0.122	-0.051	0.077	-0.25***	0.075
Early Maturity(-1=Bad, 0=Average, 1=Good)	0.893***	0.098	0.891***	0.237	0.469***	0.129	-0.50***	0.069	-0.92***	0.079
High grain yield(-1=Bad, 0=Average, 1=Good)	0.123	0.102	0.158	0.200	0.145	0.135	-0.056	0.083	-0.200**	0.082
High fodder yield(-1=Bad, 0=Average, 1=Good)	-0.213**	0.085	0.221	0.161	0.384***	0.121	0.017	0.077	0.014	0.071
Grain size(-1=Bad, 0=Average, 1=Good)	0.138	0.094	-0.176	0.167	0.239*	0.124	0.070	0.086	-0.24***	0.077
Grain color(-1=Bad, 0=Average, 1=Good)	0.259***	0.097	0.096	0.178	0.097	0.121	0.055	0.086	-0.178**	0.079
Good taste(-1=Bad, 0=Average, 1=Good)	0.080	0.105	0.060	0.191	0.233*	0.138	0.063	0.093	-0.079	0.086
Storability(-1=Bad, 0=Average, 1=Good)	-0.166*	0.099	0.214	0.203	0.150	0.129	0.049	0.088	-0.016	0.080
Cooking time(-1=Bad, 0=Average, 1=Good)	0.289***	0.096	0.164	0.185	-0.083	0.120	-0.23***	0.081	-0.162**	0.079
Selling price(-1=Bad, 0=Average, 1=Good)	0.013	0.098	-0.078	0.167	-0.240*	0.124	0.013	0.088	0.069	0.079
High head filling(-1=Bad, 0=Average, 1=Good)	0.159*	0.089	0.383**	0.177	-0.024	0.119	-0.056	0.080	-0.167**	0.073
Long head(-1=Bad, 0=Average, 1=Good)	-0.438***	0.080	-0.170	0.139	-0.132	0.104	0.376***	0.075	0.329***	0.065
Large stalk(-1=Bad, 0=Average, 1=Good)	-0.100	0.080	0.156	0.150	-0.329***	0.103	0.232***	0.076	0.266***	0.066
Easy to process(-1=Bad, 0=Average, 1=Good)	0.041	0.086	-0.002	0.164	-0.197*	0.106	-0.046	0.076	0.102	0.071
Other traits(-1=Bad, 0=Average, 1=Good)	0.271	0.212	0.018	0.354	-0.260	0.308	0.129	0.201	-0.099	0.180
state==jigawa	-0.672***	0.132	-0.61***	0.206	0.232	0.171	-0.119	0.120	0.500***	0.108
state==kano	-0.351***	0.127	-1.10***	0.259	-0.153	0.184	0.305***	0.118	0.471***	0.108
state==katsina	0.032	0.148	0.175	0.212	-0.516**	0.248	-0.141	0.148	0.084	0.125
state==yobe	-1.121***	0.295			-0.082	0.330	-1.00***	0.268	1.718***	0.197
state==zamfara	-0.176	0.131	-0.71***	0.242	0.321*	0.177	-0.145	0.128	0.205*	0.109
_cons	-1.642***	0.154	-2.72***	0.336	-2.395***	0.213	-0.58***	0.130	1.574***	0.125
Number of observations	1,699		1,634		1,699		1,699		2,507	
Pseudo R2	0.200		0.216		0.133		0.118		0.216	
note: *** p<0.01, ** p<0.05, * p<0.1										

For sorghum varieties, farmers like the insect tolerance and early maturing traits, higher fodder yield, grain color and high marketability (good market prices) of ICSV 400, but dislike the smaller stalk, shorter head and lower drought resistance. It can be noted that grain yield trait is negative but not a significant trait. Likewise, farmers have reported liking the insect tolerance and early maturing traits, but dislike the lower fodder yield, low marketability price, and shorter head and small stalk of ICSV 111. Though not significant, grain yield was not reported as significant trait driving the perception of sorghum producers. As for the variety SK 5912, producers reported its good taste as a significant desirable trait but disliked its grain color and shorter stalk.

The sorghum variety FARAFARA is highly preferred for its tolerance to insects, lower cooking time but disliked for its lower grain yield, low market price and poor head filling. Other local sorghum varieties are preferred generally for the larger grain size, loner head and larger stalk but are disliked for low tolerance to insects and longer crop maturity.

Table 10. Probit results on sorghum variety characteristics preferred by producers

Trait	ICSV 400		ICSV 111		SK5912		Farafara		Local varieties	
	Coef	**Se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Drought resistance (-1=Bad, 0=Average, 1=Good)	-0.470***	0.174	0.238	0.223	0.307	0.218	0.147	0.271	0.026	0.109
Insect tolerance(-1=Bad, 0=Average, 1=Good)	0.471***	0.174	0.407*	0.208	-0.160	0.188	0.484*	0.267	-0.30***	0.101
Early Maturity(-1=Bad, 0=Average, 1=Good)	0.835***	0.178	0.874***	0.249	0.133	0.192	-0.153	0.216	-0.53***	0.108
High grain yield(-1=Bad, 0=Average, 1=Good)	-0.028	0.187	0.283	0.228	0.141	0.227	-0.416*	0.232	-0.088	0.112
High fodder yield(-1=Bad, 0=Average, 1=Good)	0.426**	0.168	-0.320*	0.188	-0.021	0.186	-0.205	0.218	-0.116	0.093
Grain size(-1=Bad, 0=Average, 1=Good)	0.030	0.173	-0.283	0.192	-0.032	0.198	0.106	0.257	0.189*	0.097
Grain color(-1=Bad, 0=Average, 1=Good)	0.184	0.184	0.055	0.202	-0.327*	0.197	0.117	0.263	-0.142	0.104
Good taste(-1=Bad, 0=Average, 1=Good)	-0.027	0.207	-0.316	0.214	0.748***	0.268	-0.191	0.275	0.076	0.119
Storability(-1=Bad, 0=Average, 1=Good)	-0.038	0.174	0.251	0.211	0.192	0.200	0.314	0.303	0.037	0.108
Cooking time(-1=Bad, 0=Average, 1=Good)	0.004	0.183	0.154	0.217	0.024	0.199	0.759**	0.358	-0.161	0.108
Selling price(-1=Bad, 0=Average, 1=Good)	0.516***	0.186	-0.401**	0.186	-0.227	0.189	-0.439*	0.232	-0.045	0.102
High head filling(-1=Bad, 0=Average, 1=Good)	0.274	0.181	-0.004	0.195	0.251	0.204	-0.64***	0.222	-0.142	0.103
Long head(-1=Bad, 0=Average, 1=Good)	-0.290**	0.145	-0.54***	0.178	-0.012	0.181	-0.178	0.217	0.28***	0.085
Large stalk(-1=Bad, 0=Average, 1=Good)	-0.580***	0.145	-0.314*	0.180	-0.48***	0.167	0.437*	0.244	0.151*	0.086
Easy to process(-1=Bad, 0=Average, 1=Good)	0.137	0.173	-0.074	0.203	0.174	0.200	0.455	0.285	0.008	0.099
Other traits(-1=Bad, 0=Average, 1=Good)	-0.312	0.531	0.294	0.499	0.085	0.466	-1.034	2.037	0.171	0.299
state==jigawa	4.902	121.939	-0.177	0.269	5.025	258.657	4.591	249.900	-0.214	0.179
state==kano	4.940	121.939	-0.576**	0.286	3.481	258.657	4.418	249.900	-0.112	0.179
state==katsina	4.815	121.939	-0.067	0.292			4.188	249.900	-0.349*	0.196
state==yobe	4.508	121.939	-1.51***	0.456	4.358	258.657	4.214	249.900	-1.08***	0.177
state==zamfara	4.796	121.939	-0.574*	0.303	5.156	258.657	4.378	249.900	-0.090	0.189
_cons	-7.324	121.939	-1.68***	0.322	-6.907	258.657	-7.013	249.900	2.443***	0.206
Number of observations	980		980		866		980		2,541	
Pseudo R2	0.239		0.286		0.220		0.235		0.135	

note: *** p<0.01, ** p<0.05, * p<0.1

5.4. *Exposure of producers to modern sorghum and pearl millet varieties*

Exposure or awareness to modern technologies/varieties is one of the critical drivers and the first step to adoption of technologies. Farmers must first know about the technology and after take the decision to adopt or not. Table 4 shows the rate of awareness for each cultivar defined as the proportion of sorghum and pearl millet producers who have heard or seen the seeds and/or cultural management practices.

5.4.1. Knowledge of pearl millet and sorghum varieties

Among pearl millet producers, it is estimated that 43% are exposed to SOSAT C88 and 24% to ex-Borno. Fewer farmers have been exposed to other modern varieties such as ICMV-IS 89305, LCIC9702, LCIC 9703 or GB 8735. Overall, 45% of pearl millet producers were exposed to modern varieties. There are however differences between states. The rate of awareness is significantly lower in Yobe state (17%), significantly lower in Jigawa state (355) than other states where awareness is above 45%. For sorghum producers, the rates of awareness are higher for ICSV 400 known by about 18% of the surveyed farmers and for ICSV 11 also known by about 18% of surveyed households. About 30% of sorghum producers were exposed to modern varieties. Similarly as in the case of pearl millet producers, sorghum producers in Yobe and Jigawa states are less exposed to new varieties than in other states. This reflects of the strengths of the extension services in the different states.

Table 11. Proportion of farmers reporting knowing (aware or exposed) pearl millet and sorghum varieties by State in Northern Nigeria

	State						
Variables	**Borno**	**Jigawa**	**Kano**	**Katsina**	**Yobe**	**Zamfara**	**Total**
Pearl millet producers	**(114)**	**(178)**	**(252)**	**(203)**	**(115)**	**(185)**	**(1047)**
SOSAT C88	57.89	33.71	48.02	48.28	8.70	53.51	43.36
GB 8735	1.75	3.93	0.79	0.49	0.87	0.54	1.34
ICMV-IS 89305	0.00	0.00	0.00	0.00	4.35	0.00	0.48
LCIC 9702	0.00	0.00	0.00	0.00	1.74	1.08	0.38
LCIC 9703	0.00	0.56	0.00	0.00	3.48	0.00	0.48
Zatib	0.00	1.12	0.00	0.00	0.00	0.00	0.19
Ankoutess	0.00	0.56	0.00	0.49	0.00	0.54	0.29
Ex-Borno	19.30	42.70	14.68	20.20	3.48	38.38	23.97
Gwa-Gwa	7.02	1.12	0.40	0.00	33.04	1.08	4.87
ICRISAT varieties	58.77	34.83	48.41	48.77	17.39	53.51	44.79
Other varieties	71.05	65.73	75.00	79.80	95.65	82.16	77.46
Sorghum producers	**(139)**	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**
ICSV 400	3.62	17.58	25.68	17.21	7.69	28.02	18.34
ICSV 111	27.54	15.15	8.56	37.21	4.27	10.44	17.60
ICRISAT hybrid sorghum	0.00	3.64	0.00	0.00	13.68	1.65	2.33
SK 5912	0.73	9.70	2.34	0.00	5.98	30.77	8.01
Kaura	18.84	61.21	75.49	32.56	42.74	32.97	46.65
Farafara	0.73	35.76	19.07	7.44	2.56	0.00	11.92
Bargonzaki	0.00	30.30	35.02	49.77	7.69	38.46	30.35
ICRISAT varieties	29.50	22.02	31.27	41.86	19.66	29.51	30.16
Other varieties	92.09	88.69	96.53	93.49	100.00	97.27	94.64

Sample size in parentheses

5.5. Adoption of pearl millet and sorghum varieties

Awareness is highly correlated with adoption of technologies and innovations. It is estimated that about 38% of pearl millet producers have adopted modern varieties. This accounts for about 84% of the producers that have been exposed to modern varieties. Similarly, 25% of sorghum producers have adopted modern varieties accounting for about 83% of producers that have been aware of modern sorghum varieties.

5.5.1. Proportion of farmers having adopted improved pearl millet or sorghum varieties

Table 5 presents the proportion of farmers having adopted modern varieties by state and variety. Same as awareness, except for Yobe and Jigawa states, where the proportion of adopters of pearl millet varieties is lower, 11% and 28% respectively, adoption is above 43% in other states.

Table 12. Proportion of farmers having adopted pearl millet and sorghum varieties in selected stated in Northern Nigeria

	State						
Variety	**Borno**	**Jigawa**	**Kano**	**Katsina**	**Yobe**	**Zamfara**	**Total**
Pearl millet	**(114)**	**(178)**	**(252)**	**(203)**	**(115)**	**(185)**	**(1047)**
SOSAT C88	44.74	27.53	43.25	44.33	5.22	44.86	37.06
GB 8735	0.88	2.81	0.40	0.00	0.87	0.00	0.76
ICMV-IS 89305	0.00	0.00	0.00	0.00	2.61	0.00	0.29
LCIC 9702	0.00	0.00	0.00	0.00	0.87	0.00	0.10
LCIC 9703	0.00	0.00	0.00	0.00	2.61	0.00	0.29
Zatib	0.00	1.12	0.00	0.00	0.00	0.00	0.19
Ankoutess	0.00	0.56	0.00	0.49	0.00	0.00	0.19
Ex-Borno	13.16	39.89	12.30	12.81	3.48	30.81	19.48
Gwa-Gwa	6.14	1.12	0.00	0.00	31.30	0.54	4.39
ICRISAT varieties	45.61	28.09	43.25	44.33	11.30	44.86	37.92
Other varieties[1]	67.54	58.43	69.44	71.92	86.96	65.41	69.05
Sorghum	**(139)**	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**
ICSV 400	2.16	14.88	22.39	11.16	5.98	20.22	14.25
ICSV 111	23.02	14.29	6.56	33.02	3.42	6.01	14.71
ICRISAT hybrid sorghum	0.00	2.98	0.00	0.00	0.86	1.09	0.74
SK 5912	0.72	8.33	0.77	0.00	4.27	25.14	6.29
Kaura	16.55	51.19	73.36	28.84	38.46	26.23	42.00
Farafara	0.00	32.14	16.22	6.98	0.00	0.00	10.27
Bargonzaki	0.00	17.26	22.39	26.05	5.98	27.87	18.59
ICRISAT varieties	24.46	20.24	27.03	40.00	8.55	22.40	25.44
Other varieties	89.928	82.143	95.367	91.163	99.145	89.071	91.119

1. Sample size in parentheses

5.5.2. Area planted with improved varieties in Northern Nigeria

Area planted under new varieties is the most important indicator of adoption of varieties. The rate of pearl millet adoption of new varieties is calculated as the ratio of area planted under the modern varieties over the total area planted to sorghum. The rate of adoption of new varieties is closely correlated to the rate of awareness. Table 6 summarizes the rates of adoption of sorghum and pearl millet varieties by state and by variety. It is estimated about 25% of pearl millet area is planted with modern varieties. The variety SOSAT C88 is overwhelmingly the most adopted

[1] Other varieties refer to local or improved varieties released before 1996.

accounting for more than 95% of area planted with new varieties in the 6 states. Likewise, lower adoption rates are recorded in Yobe and Jigawa, 6% and 15 respectively against more than 28% in other states. As for sorghum producers, overall 17% of sorghum area is planted with modern varieties. The varieties ICSV400 and ICSV111 are the dominated varieties accounting for 8% and 9% of area planted with modern varieties respectively. Other modern sorghum varieties include ICRISAT hybrids and the open-pollinated variety SK 5912 accounting for 0.27% and 2.75% of area planted respectively.

Table 13. Proportion of area planted with alternative pearl millet and sorghum varieties in selected States in Northern Nigeria

	State						
Variables	**Borno**	**Jigawa**	**Kano**	**Katsina**	**Yobe**	**Zamfara**	**Total**
Pearl millet producers	**(114)**	**(178)**	**(252)**	**(203)**	**(115)**	**(185)**	**(1047)**
SOSAT C88	27.08	13.53	30.09	32.76	1.87	27.73	23.95
GB 8735	0.88	1.22	0.00	0.00	0.00	0.00	0.30
ICMV-IS 89305	0.00	0.00	0.00	0.00	2.03	0.00	0.22
LCIC 9702	0.00	0.00	0.00	0.00	0.43	0.00	0.05
LCIC 9703	0.00	0.00	0.00	0.00	1.59	0.00	0.18
Zatib	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Ankoutess	0.00	0.28	0.00	0.00	0.00	0.00	0.05
Ex-Borno	5.23	31.48	9.94	4.68	0.77	15.98	12.13
Gwa-Gwa	4.04	0.51	0.00	0.00	23.83	0.08	3.16
ICRISAT varieties	27.95	14.76	30.09	32.76	5.93	27.73	24.70
Other varieties	40.50	42.80	54.82	55.17	78.52	43.32	51.86
Sorghum producers	**(139)**	**(168)**	**(259)**	**(215)**	**(117)**	**(183)**	**(1081)**
ICSV 400	1.80	7.79	12.25	7.84	2.20	12.86	8.35
ICSV 111	13.78	9.12	2.52	20.95	1.42	3.15	8.65
ICRISAT hybrid sorghum	0.00	1.14	0.00	0.00	0.43	0.27	0.27
SK 5912	0.48	4.23	0.39	0.00	1.31	10.67	2.76
Kaura	6.80	24.87	51.09	13.23	25.78	12.21	24.47
Farafara	0.00	23.18	5.69	1.06	0.00	0.00	5.18
Bargonzaki	0.00	6.02	8.69	3.50	3.51	10.66	5.90
ICRISAT varieties	15.58	18.05	14.77	28.79	4.06	16.28	17.27
Other varieties	64.19	17.11	18.53	48.31	65.35	35.95	38.12

Sample size in parentheses

5.6. Determinants of exposure to improved pearl millet and sorghum varieties

The determinants of household exposure to improved pearl millet and sorghum varieties, estimated using propensity score matching (PSM) method, are presented in Tables 7 and 8. In these probit regression models, we include most of the household characteristics discussed in Table XX as determinants of exposure.[2] For endowments that change over time (e.g., asset values, education, etc.), we use the level of the endowment in 1999/00 to reduce potential

[2] We did not include the primary occupation of the household head because there was little variation in this among households, as observed in Table 4.6. We did not include the value of remittances or credit received, as these were considered to be even more subject to endogeneity concerns than endowments. We did not include participation in technology transfer programs during the past five years, as this is largely affected by SLM program participation and hence endogenous.

endogeneity bias caused by the endowments being affected by exposure.[3] We include state fixed effects to account for state level factors that may influence exposure to modern varieties.

Household exposure to pearl millet varieties is significantly (at 10% level or less) influenced by the number of varieties known in the village (+), the value of pearl millet sold (+), the area planted with pearl millet (+), the total household work force, proxied by the number of adult equivalents (+) and the value of equipment (+). In addition, results indicate that Borno State, households were less exposed to improved pearl millet varieties in Yobe and Zamfara States. Households who have received training in business, crop management and seed production techniques are more exposed to improved pearl millet varieties.

These results indicate that exposure to modern varieties is greater among households with more physical, human and social capital. Perhaps households with more and better land feel less need to adopt improved varieties. Next we assess the factors driving adoption of improved pearl millet varieties using the Average Treatment Effect corrected approach.

Table 14. Logistic estimation results of the determinants of the probability of exposure to pearl millet varieties

	Estimates	
	Coef.	Std. Err.
Number of pearl millet varieties known in the village	0.9653093***	0.0744054
Number of traditional varieties known	-0.0468979	0.0304808
Log of farm size	-0.1150188	0.0787506
Pearl millet area share	-0.0822863	0.1128017
Log of total cash income in 1999	0.0040214	0.0097521
Idle area (non-cultivated) share in 1999	-5.42E-02	2.66E-01
Log of value of pearl millet sold in 1999	2.74E-06**	1.20E-06
Area planted with pearl millet	0.0827216***	0.0305011
Age of household head in 2008/09	0.0042766	0.0047032
Education of household head in 2008/09	0.0192575	0.0276222
Total work force (adult equivalents)	0.2675478***	0.0770557
Log of value of equipment in 2008/09	0.0429173**	0.0189512
Household size in 2008/09	0.0042329	0.0099223
Nigeria state (compared to Borno State)		
Jigawa	-0.0263872	0.2110158
Kano	-0.3316249	0.2077621
Katsina	-0.2126827	0.1897826
Yobe	-0.747521***	0.2306175
Zamfara	-0.4295618**	0.2188553
Has tested modern varieties? (0=No, 1=yes)	0.4600331***	0.1764637
Has received training in plot management? (0=No, 1=yes)	0.3092333*	0.1807545
Has received training in seed production techniques? (0=No, 1=yes)	0.3731374*	0.1932576
Has received training in crop production?	1.097907**	0.4701581
Constant	-2.249657***	0.4358795

[3] Since some programs began before 2001, there is still potential endogeneity in the endowments as of 2001 for those programs. We are unable to solve this problem for older programs such as PGRN, so the results for these programs must be interpreted with this in mind.

Cragg-Uhler(Nagelkerke) R-square	0.438
ML (Cox-Snell) R2:	0.327
Log likelihood	-452.42598
Goodness of fit	368.41

Notes.
1.Dependent variable: Dummy variable indicating Knowledge of at least one modern pearl millet variety
***, **, and * represent statistical significance at 1%, 5% and 10%, respectively.

Household exposure to sorghum varieties is significantly (at 10% level or less) influenced by the number of sorghum varieties known in the village (+), the number of traditional sorghum varieties known (-), the value of sorghum sold (+),age of household head (-) and area planted with sorghum (-). Compared to Borno state, other states surveyed (Jigawa, Kano, Katsina and Zamfara) are more exposed to improved sorghum varieties (+). This may be explained by the stronger extension services in other states than Borno. Results showed that the probability of exposure decreases with training in seed production techniques and increases with farmer's participation in varietal testing. This may also be explained by the fact that those trained may have tested modern sorghum varieties and have found those be less performing than the old varieties they owned.

Table 15. Logistic estimation results of the determinants of the probability of exposure to modern sorghum varieties

	Estimates	
	Coefficient	Std. Err.
Number of sorghum varieties known in the village	0.429073***	0.05116
Number of traditional sorghum varieties known	-0.13493***	0.040218
Log of farm size	0.129965	0.093506
Sorghum area share 1999	0.013313	0.038474
Idle area (non-cultivated) share in 1999	0.25573	0.250684
Log of total cash income in 1999	1.11E-02	1.08E-02
Value of sorghum sale 1999	6.40E-06**	2.80E-06
Area planted with sorghum	-0.04196*	0.023754
Age of household head	0.013894**	0.005778
Education of household head 2008/09	0.047478	0.030338
Total work force 2008/09	0.012069	0.090749
Log of value of equipment 2008/09	0.03511	0.023141
Household size	0.006918	0.012762
Nigeria State (compared to Borno State)		
Jigawa	1.016209***	0.227566
Kano	1.427046***	0.2552
Katsina	0.797151***	0.187116
Yobe	0.175982	0.196707
Zamfara	0.696548***	0.239378
Has tested modern varieties? (0=No, 1=yes)	0.103998	0.27377
Has received training in seed production techniques? (0=No, 1=yes)	-0.87049***	0.251635
Constant	-2.12601***	0.458855
Cragg-Uhler(Nagelkerke) R-square	0.345	
ML (Cox-Snell) R2:	0.244	
Log likelihood	-355.429	
Goodness of fit	368	

Notes.
1.Dependent variable: Dummy variable indicating Knowledge of at least one modern sorghum variety
***, **, and * represent statistical significance at 1%, 5% and 10%, respectively.

5.7. Results of the adoption rate and the determinants of adoption of modern pearl millet and sorghum varieties

Tables 9 and 10 present the estimated results of the determinants of adoption of pearl millet and sorghum with ATE corrected Poisson model. Table 11presents the current and potential adoption rates of pearl millet and sorghum.

5.7.1. Determinants of adoption

In many studies of adoption, simple logit models are often used to assess the determinants of adoption. This produces bias and inconsistent estimates of drivers of adoption. Without the corrected logit, probit or Poisson-ATE procedure, it will not be possible to produce consistent estimates of the coefficients of the determinants of the probability of adoption (Diagne, A. 2006). This study used the ATE corrected Poisson regression to assess the determinants of adoption of pearl millet and sorghum varieties in Nigeria.

The determinants of adoption of pearl millet varieties are identified as the knowledge of varieties (+), the number of traditional varieties known (+), the area planted with pearl millet (+), education of household head (+) and household total work force (+). Compared to Borno State, farmers have adopted significantly more in Kano and Zamfara States. Training in crop and seed production techniques are significantly important in explaining the probability of adoption.

Table 16. Results of Estimation of the determinants of Pearl millet variety adoption with correction for the non-exposure and population selection biases

	ATE-Corrected	
	Coefficient	Robust Std. Err.
Knowledge of pearl millet varieties by the farmer	18.1251***	0.0661369
Number of pearl millet varieties cultivated	0.0829491	0.0521236
Number of traditional varieties known	0.0297896*	0.0173086
Log of farm size	-0.0171075	0.0511528
Pearl millet area share	0.0940205	0.0653375
Log of total cash income in 1999	-1.63E-03	6.02E-03
Log of value of pearl millet sold in 1999	6.10E-07	6.36E-07
Age of household head	-0.0037664	0.0029116
Area planted with pearl millet	0.0393195***	0.0118593
Education of household head	0.0307339**	0.0148115
Total work force	0.1227223**	0.0501232
Household size	-0.0054065	0.0059538
Log of value of equipment	-0.0133131	0.0109107
Nigeria state (compared to Borno state)		
Jigawa	0.17742	0.1332702
Kano	0.3361563***	0.1274698
Katsina	0.1990165	0.1312379
Yobe	-0.0813888	0.222278

Zamfara	0.6225082***	0.1257448
Has tested modern varieties? (0=No, 1=yes)	-0.0544557	0.0833053
Has received training in plot management? (0=No, 1=yes)	-0.0442966	0.1088405
Has received training in seed production techniques? (0=No, 1=yes)	0.247054***	0.0857376
Has received training in crop production?	0.4663568***	0.1340109
Constant	-18.96362***	0.2655702
Log pseudo-likelihood		-525.893
F-statistics (931, 22) Wald chi2(22)		543917.12
Pseudo R2		0.3275
Prob. > chi2		0.0000

Notes.
1.Dependent variable: Number of modern pearl millet varieties cultivated by the farmer in 2008/09
***, **, and * represent statistical significance at 1%, 5% and 10%, respectively.

The determinants of adoption of sorghum varieties include the knowledge of modern sorghum varieties (+), the number of sorghum varieties planted by the farmer (+), the number of traditional varieties known (-), the log of farm size (+), the share of non-cultivated are available to households (+) and the age of household head (+). Compared to Borno State, the probability of adoption Jigawa, Kano, Yobe and Zamfara. Training in seed production techniques (+) positively affect the probability of adoption of sorghum varieties.

Table 17. Results of Estimation of the determinants of sorghum variety adoption with correction for the non-exposure and population selection biases

	ATE-Corrected	
	Coefficient	Robust Std. Err.
Knowledge of modern sorghum varieties by the farmer	17.24612***	0.086662
Number of sorghum varieties cultivated	0.48206***	0.043436
Number of traditional sorghum varieties known	-0.31177***	0.053979
Log of farm size	0.227239***	0.085916
Sorghum area share in 1999	5.44E-02*	3.32E-02
Log of value of equipment	4.53E-02	2.81E-02
Idle area (non-cultivated) share in 1999	0.450523*	0.244763
Log of total cash income in 1999	-0.00225	0.011177
Value of sorghum sale in 1999	2.11E-06	2.35E-06
Age of household head in 2008/09	-0.00916*	0.005375
Education of household head in 2008/09	-0.02122	0.030675
Total work force in 2008/09	0.050768	0.096099
Area planted with sorghum	-0.0061	0.026619
Household size in 2008/09	-0.01386	0.010941
Nigeria State (compared to Borno State)		
Jigawa	-1.69016***	0.256151
Kano	-0.99468***	0.235957
Katsina	-0.01713	0.179161
Yobe	-0.58891*	0.305561
Zamfara	-0.83497***	0.2615
Has tested modern varieties? (0=No, 1=yes)	0.010014	0.219382
Has received training in seed production techniques? (0=No,	0.858494***	0.230887

1=yes)		
Constant	-19.2805***	0.44845
Log pseudo-likelihood		-437.934
F-statistics (931, 22) Wald chi2(22)		125353.1
Pseudo R2		0.2436
Prob > chi2		0.000

Notes.
1.Dependent variable: Number of modern sorghum varieties cultivated by the farmer in 2008/09
***, **, and * represent statistical significance at 1%, 5% and 10%, respectively.

5.7.2 Current and full population adoption of modern sorghum and pearl millet varieties

Table 11 presents the predicted sorghum and pearl millet probability of adoption with the Average Treatment Effect (ATE) correction for non-exposure and population biases estimates. The current population adoption rates for sorghum and pearl millet are estimated about 23% and 35% respectively. However the population quantity being estimated is both the population exposure and adoption rate. In fact, these estimates are not the population quantities one would think about. One should be estimating the full population adoption rate. In this case the full population adoption rate for modern pearl millet varieties is estimated to about 59% for first time or repeat adoption in year 2008/09. This means that 59% of the pearl millet producers would be found to have adopted pearl millet varieties in 2008/09 if the full population has been exposed to modern pearl millet varieties by 2008/09. The ATE full population adoption rate estimate implies that a very large negative non exposure bias of -24% when the sample estimate of the incomplete population adoption rate is wrongly used.

Table 18. Current and potential adoption of modern pearl millet and sorghum varieties based on awareness or promotion of varieties

	Parameter	Robust Std. Err.
Pearl millet		
Population adoption rate	0.5859751***	0.0266244
Current adoption rate	0.3480129***	0.0127333
Adoption gap	-0.2379623***	0.0172742
Observed		
Number of exposed /Number of farmers	0.5682062***	0.0162424
Number of adopters/Number of farmers	0.3480129***	0.0156198
Number of adopters / number of exposed	0.6124764***	0.0274897
Sorghum		
Population adoption rate	0.272418***	0.014408
Current adoption rates	0.229042***	0.011398
Adoption gap	-0.04338***	0.004388
Observed		
Number of exposed /Number of farmers	0.774264***	0.013813
Number of adopters/Number of farmers	0.230098***	0.013907
Number of adopters / number of exposed	0.297183***	0.017961

For sorghum producers, the full population adoption rate for modern sorghum varieties is estimated to about 27% for first time or repeat adoption in year 2008/09. This means that 27% of the sorghum producers would be found to have adopted pearl millet varieties in 2008/09 if the full population has been exposed to modern pearl millet varieties by 2008/09. The ATE full population adoption rate estimate implies that a very small negative non exposure bias of -4% when the sample estimate of the incomplete population adoption rate is wrongly used. This means that there is little difference between the current and the full population adoption rate and therefore little room to increasing adoption of modern sorghum varieties. Further investments in promotion or awareness will not increase much the adoption of current modern sorghum varieties.

5.8. Economic impacts of modern pearl millet and sorghum varieties on household livelihood outcomes

The economic impacts of household adoption of pearl millet and sorghum varieties were estimated using the PSM and econometric methods described in the methodology section and summarized in Tables 12 and 13 respectively.

5.8.1. Impacts of modern varieties on household livelihood outcomes: matching methods

Impact on modern pearl millet varieties

Table 14 presents the results for the impact of adoption of pearl millet varieties on livelihood outcomes using 5 methods namely the propensity score matching using nearest neighborhood (PSM-NN), the propensity score matching using kernel algorithm(PSM-Kernel), the bias-adjusted NN match estimates, the simple regression and the instrumental variable approaches. All five estimation methods show a significant and positive impact of modern pearl millet varieties' adoption on household average crop yield, per capita gross income, per capita value of crop production and cereal self-sufficiency proxied by the per capita quantity of cereal production. However, no significant impact was found on the number of hungry months another indicator for food self-sufficiency, per capita household wealth or household per capita expenditure. As for the total value of sale, differences were found using the PSM methods.

The magnitudes of the statistically significant impacts on per capita gross income or per capita value of production are quite substantial. For example, the coefficient of 0.419 for the impact of adoption in the PSM-NN model implies that the mean value of per capita gross income is 52% higher for household adopters and similar household non-adopters (exp (0.419)=1.52). Overall, using the 5 methods, the estimated impacts of adoption of pearl millet varieties are between 34% and 76% for adopters than similar household non-adopters. Similarly the estimated impacts of adoption on the per capita total value of production are 48% to 101% higher for adopters than similar household non-adopters.

Our best estimates showed that the household average pearl millet yield varies between 88 kg/ha to 157 kg/ha. Per capita gross income varies between naira to Naira (USD to USD). The per capita value of crop production varies between Y and. .Z. On average, household adopters of modern pearl millet varieties generate between 127 kg/person/year of cereals and 230 kg/person/year more than non-adopters. However, there were no significant differences between adopters and non-adopters based on the number of hungry months, per capita wealth or per capita expenditure. This may indicate that adoption of modern pearl millet varieties had little impacts on poverty reduction.

Table 19. Impacts of adoption of modern pearl millet varieties estimated by matching methods

Variable	Estimation methods	*Household level impacts*	
		Estimated impacts	*Estimated Standard Error*
Crop yield (Kg/ha)	NN matching	88.821**	51.126 (1.74)
	Kernel matching	88.400**	38.658 (2.29)
	Bias-adj NN matching	89.005**	39.153
Log(Per capita total revenues – gross income (Naira))	NN matching	0.419***	0.193
	Kernel matching	0.352***	0.126
	Bias-adj NN matching	0.381***	0.129
Ln(Per capita value of pearl millet sale (Naira))	NN matching	0.901**	0.471
	Kernel matching	0.617**	0.353 (1.75)
	Bias-adj NN matching	0.318	0.343
Ln(Per capita total value of production (Naira))	NN matching	0.657***	0.237 (2.77)
	Kernel matching	0.472***	0.155
	Bias-adj NN matching	0.393**	0.159
Ln(Per capita total wealth (Naira))	NN matching	-0.042	0.109
	Kernel matching	0.018	0.082
	Bias-adj NN matching	0.043	0.076
Quantity of cereals per capita (kg/person/year)	NN matching	167.479***	42.561
	Kernel matching	145.337***	35.862
	Bias-adj NN matching	155.822***	35.503
Number of hunger months	NN matching	-0.089	0.103
	Kernel matching	-0.068	0.077
	Bias-adj NN matching	-0.124*	0.077
Per capita expenditure	NN matching	0.061	0.127
	Kernel matching	0.116	0.096
	Bias-adj NN matching	0.123	0.089

*** significant at 1%, ** significant at 5% and * significant at 10%

Source: Authors' own calculations.

Comparisons of the unmatched and matched samples using PSM are provided in Annex 1. In almost all cases the adopters and non-adopters sample households are more similar in the matched sample than in the non-matched sample in terms of observed characteristics, and the differences in the matched sample are almost always statistically insignificant (unlike the unmatched samples which are in many cases statistically different). This indicates that propensity score matching substantially improves the comparability of the samples. Nevertheless, there are still some significant differences remaining in the matched samples, which could lead to biases in the PSM results. The bias-corrected NN estimator addresses this concern. However, as discussed in the methodology section, the distance metric used for this estimator is more arbitrary than the PSM metric. Hence, we report the results of both estimators.

Impact of modern sorghum varieties

The estimated impacts of adoption of sorghum varieties based on 5 livelihood outcomes (yield, gross income, are presented in Table 15. To ensure the robustness of the results, 5 estimation methods namely the propensity score matching using nearest neighborhood (PSM-NN), the propensity score matching using kernel algorithm (PSM-Kernel), the bias-adjusted NN match estimates, the simple regression and the instrumental variable approaches were used. All five estimation methods show no significant and positive impact of modern sorghum varieties' adoption on household average crop yield, per capita gross income, per capita value of crop production and cereal self-sufficiency proxied by the per capita quantity of cereal production. No significant impact was also found on the number of hungry months another indicator for food self-sufficiency, per capita household wealth or household per capita expenditure. As for the total value of sale, differences were found using the PSM methods.

Our best estimates showed that the household average sorghum yield varies between -33 kg/ha to -14kg/ha between adopters and non-adopters but not statistically significant. Similarly, per capita gross income varies between Naira to Naira (USD to USD). The per capita value of crop production varies between Y and. .Z. On average, household adopters of modern pearl millet varieties generate between 127 kg/person/year of cereals and 230 kg/person/year more than non-adopters. However, there were no significant differences between adopters and non-adopters based on the number of hungry months, per capita wealth or per capita expenditure. This may indicate that adoption of modern sorghum varieties had little impacts on poverty reduction or food security.

Table 20. Impacts of adoption of modern sorghum varieties on household livelihood outcomes estimated by matching methods

Variable	Estimation methods	Household level impacts	
		Estimated impacts	**Estimated Standard Error**
Crop yield (Kg/ha)	NN matching	-30.135	51.327
	Kernel matching	-37.493	35.595
	Bias-adj NN matching	-14.389	33.975
Log(Per capita total revenues (FCFA))	NN matching	0.049	0.196
	Kernel matching	0.215*	0.141 (1.53)
	Bias-adj NN matching	0.172	0.151
Ln(Per capita value of pearl millet sale (Naira))	NN matching	0.023	0.534
	Kernel matching	0.065	0.390
	Bias-adj NN matching	-0.257	0.375
Ln(Per capita total value of production (Naira))	NN matching	0.021	0.213
	Kernel matching	0.183	0.170
	Bias-adj NN matching	0.125	0.169
Ln(Per capita total wealth (Naira))	NN matching	0.028	0.124
	Kernel matching	0.097	0.088
	Bias-adj NN matching	0.119	0.091
Quantity of cereals per capita (kg/person/year)	NN matching	-3.785	54.302
	Kernel matching	6.433	38.755
	Bias-adj NN matching	16.403	36.194
Number of hunger months	NN matching	0.070	0.122
	Kernel matching	0.048	0.091
	Bias-adj NN matching	0.089	0.093
Per capita expenditure	NN matching	0.055	0.134
	Kernel matching	0.068	0.099
	Bias-adj NN matching	-0.004	0.098

***,* mean statistically significant at 1% and 10%

Comparisons of the unmatched and matched samples using PSM are provided in Annex 2. In almost all cases the adopters and non-adopters sample households are more similar in the matched sample than in the non-matched sample in terms of observed characteristics, and the differences in the matched sample are almost always statistically insignificant (unlike the unmatched samples which are in many cases statistically different). This indicates that propensity score matching substantially improves the comparability of the samples. Nevertheless, there are still some significant differences remaining in the matched samples, which could lead to biases in the PSM results. The bias-corrected NN estimator addresses this concern. However, as discussed in the methodology section, the distance metric used for this estimator is more arbitrary than the PSM metric. Hence, we report the results of both estimators.

In almost all cases, the estimated impacts are quite similar using the two matching methods. Adoption of pearl millet varieties is found to significantly increase the mean value of yield, crop production, gross revenues, and per capita cereal availability.

Figure 6: Propensity score distribution and common support for propensity score estimation.

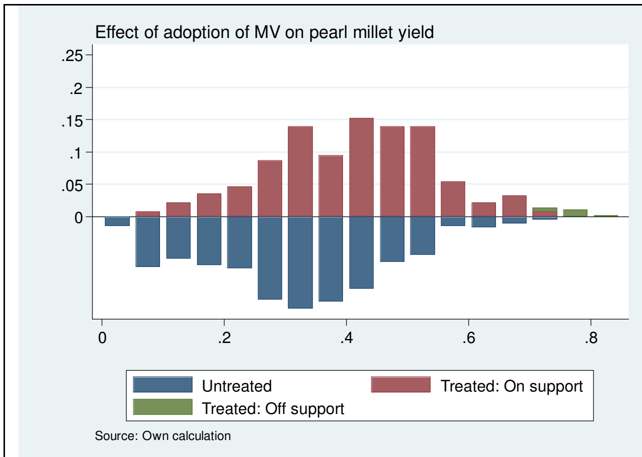


Fig.5a. Case of pearl millet yield

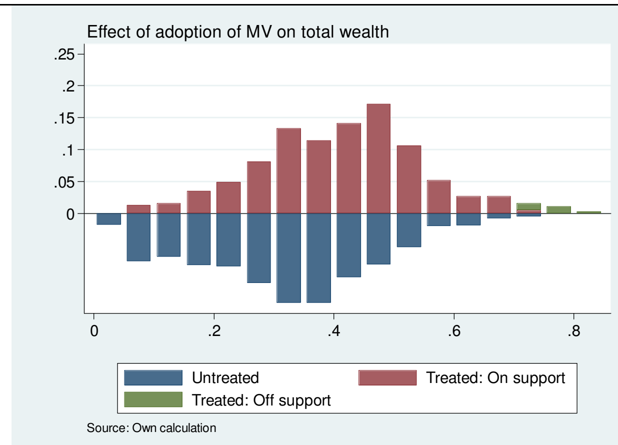


Fig. 5b. Case of per capita wealth of pearl millet producers

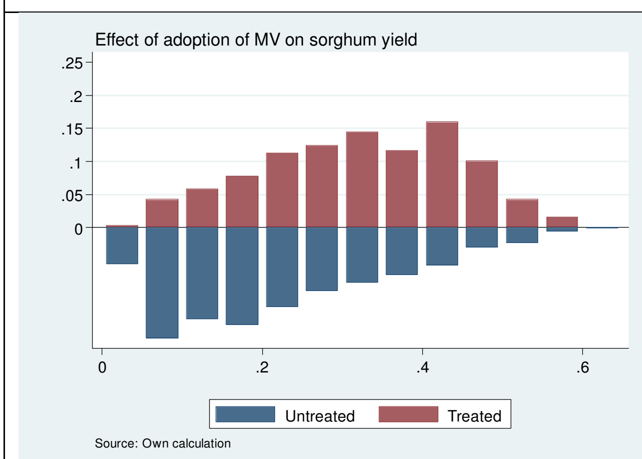


Fig. 5c. Case of sorghum yield

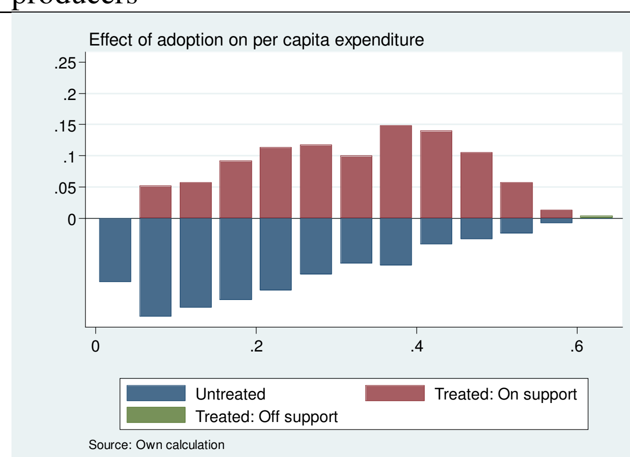


Fig. 5d. Case of per capita wealth of sorghum producers

5.8.2. Cumulative density function (CDF) of outcomes between adopters and matched non-adopters

Adoption of modern pearl millet or sorghum varieties may also affect other moments of the distribution of livelihood outcomes eg. Yield besides the mean; e.g., they may also affect the variance of production. To visually investigate such impacts, we have plotted graphs of the cumulative density function (cdf) of livelihood outcomes for matched households adopters and non-adopters (Figures 4a. to 4.f). These figures demonstrate that adoption of modern pearl millet varieties has a strongly significant positive impact on mean yield, shift the entire distribution of production to the right, which implies a lower risk of low yield (for any yield threshold) for adopters and non-adopters of modern pearl millet varieties.[4] Similar results are found for the cdf for per capita total value of production, per capita gross revenue, per capita cereal availability and per capita pearl millet sales[5].

It can be seen that adoption of modern pearl millet varieties has insignificant impacts on per capita expenditures, per capita wealth or number of hungry months. There is little systematic differences in the shape or location of the distribution functions. Hence adoption of modern varieties has little apparent impacts on production risk as well as on mean production.

Figure 7.Cumulative density functions (CDFs) of pearl millet yield, total value of production, total revenues, total wealth and value of pearl millet sales on matched households adopters and non-adopters

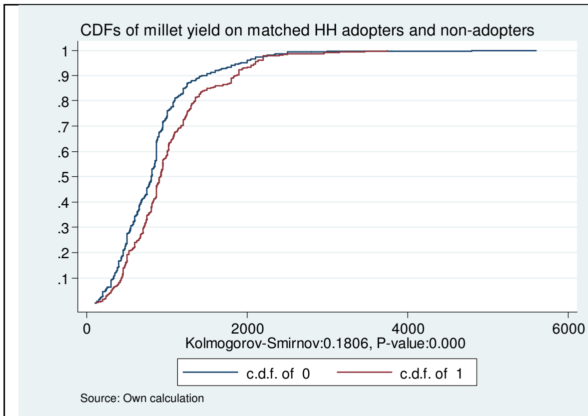


Fig 6a. CDF of pearl millet yield on matched HH adopters and non-adopters

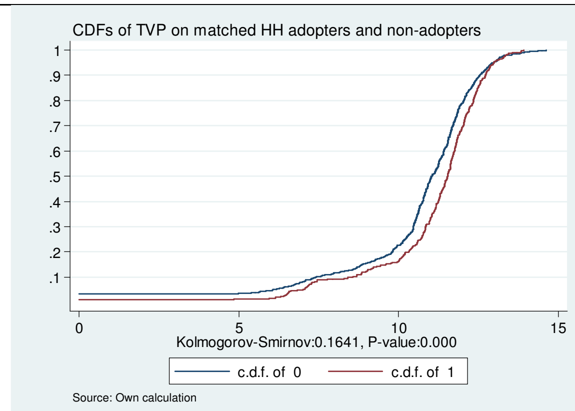


Figure 6b. CDF of total value of crop production on matched adopters and non-adopters

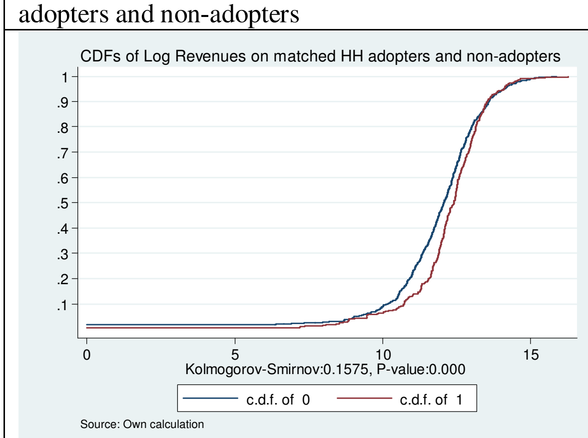


Fig 6c. CDF of per capita revenues on matched adopters and non-adopters

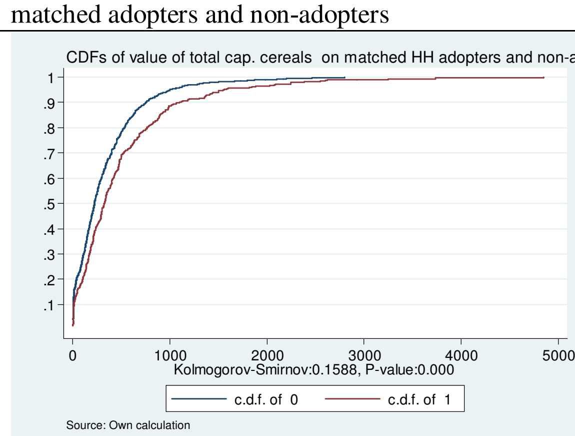


Fig. 6d. CDF of per capita cereals availability on matched adopters and non-adopters

[4] In technical terms, the distributions with these practices demonstrate first order stochastic dominance over the distributions without these practices (Mas-Colell *et al.* 1995).

[5] The differences between the distributions between adopters and matched non-adopters are statistically significant at less than 1% level for pearl millet yield, at less than 1% level for per capita total value of production, at less than 1% level for per capita revenues, per capita cereals and per capita sale (based on the Kolmogorov-Smirnov test for equality of distributions). For the other outcome variables, such as wealth, number of hungry months, or expenditures, the differences between the distributions between adopters and non-adopters were not statistically significant.

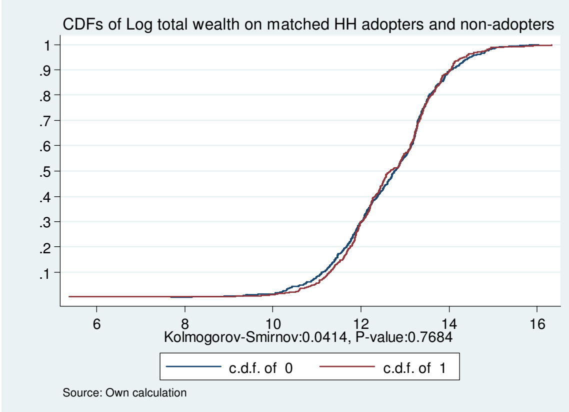


Fig 6e. CDF of per capita wealth on matched adopters and non-adopters

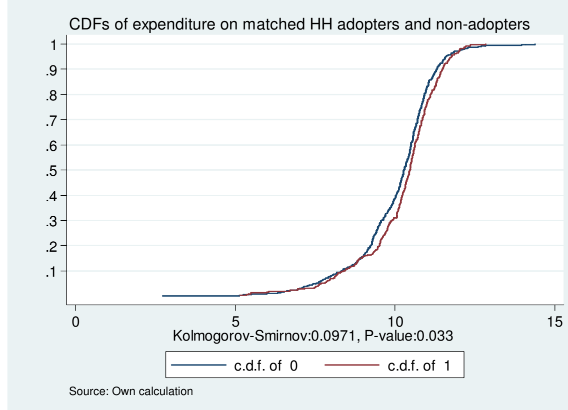


Fig 6f. CDF of per capita expenditure on matched adopters and non-adopters

The situation is different for the impact of adoption of modern sorghum varieties. Cumulative density functions (CDFs) are presented in Figures 5a. to 5f. below. These figures demonstrate that adoption of modern sorghum varieties has no significant positive impact on all livelihood outcomes except for per capita expenditure[6]. Hence adoption of modern varieties has little apparent impacts on production risk as well as on mean production.

Figure 8.Cumulative density functions (CDFs) of sorghum yield, total value of production, total revenues and total wealth on matched households adopters and non-adopters of modern sorghum varieties

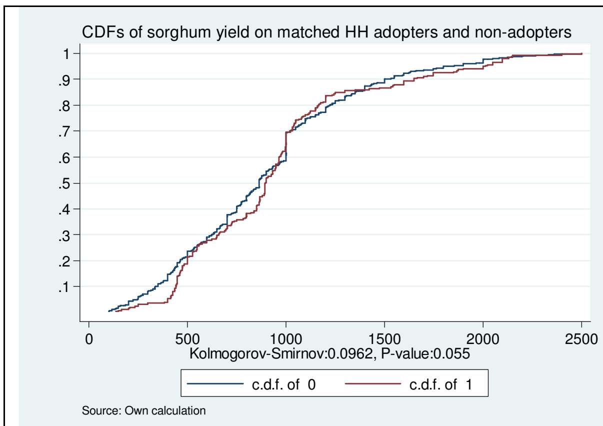


Fig. 7a. CDF of sorghum yield on matched HH adopters and non-adopters

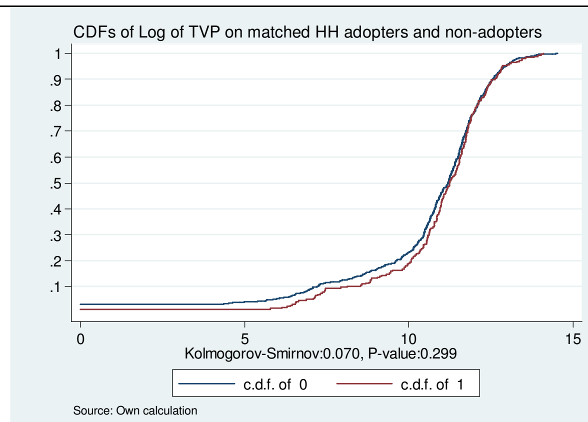


Fig. 7b. CDF of total value of crop production on matched adopters and non-adopters

[6] The differences between the distributions between adopters and matched non-adopters of sorghum varieties are statistically insignificant at less than 1% level for all livelihood outcomes. It must be noted that the CDFs of household adopters and matched non-adopters based on per capita expected are significantly different at 5% level and 10% for sorghum yield (based on the Kolmogorov-Smirnov test for equality of distributions).

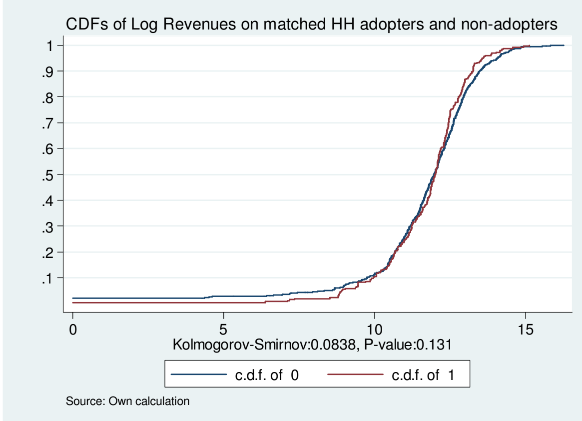


Fig. 7c. CDF of per capita revenues on matched adopters and non-adopters

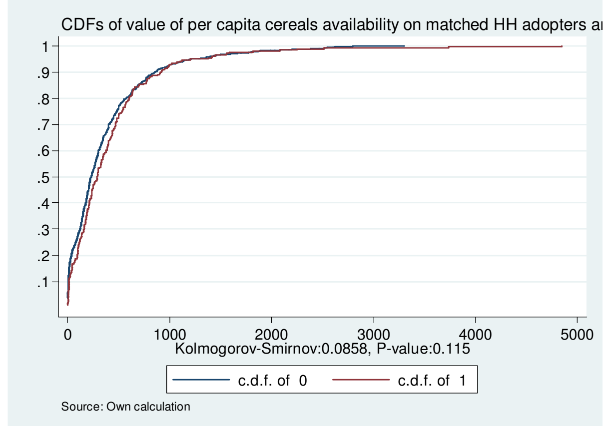


Fig. 7d. CDF of per capita cereals availability on matched adopters and non-adopters

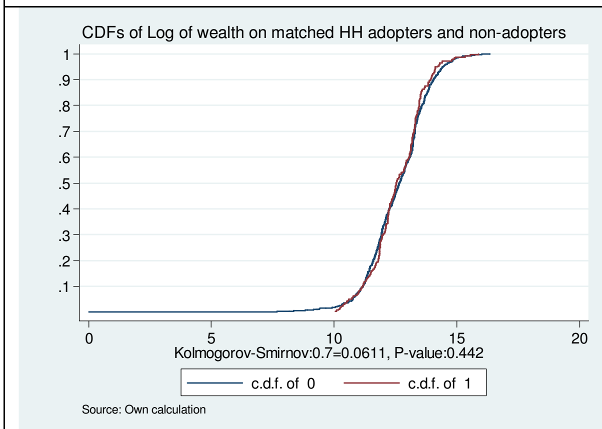


Fig. 7e. CDF of per capita wealth on matched adopters and non-adopters

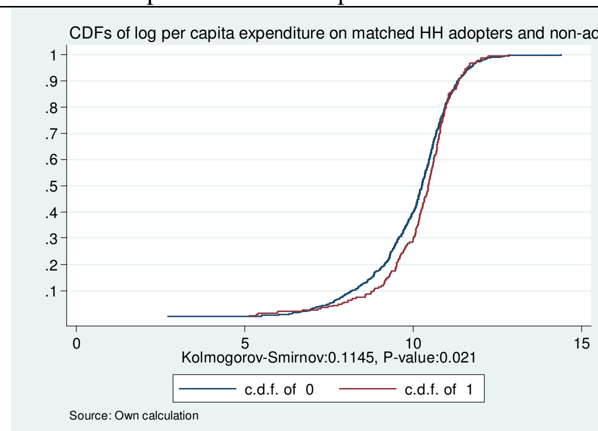


Fig. 7f. CDF of per capita expenditure on matched adopters and non-adopters

Impacts of adoption of modern pearl millet and sorghum varieties on household livelihood outcomes – Econometric Results

The estimated impacts on livelihood outcomes are summarized in Table 19 and detailed in Annexes 1 through 13. Three regression models are reported in each of the Annexes: i) an unrestricted ordinary least squares (OLS) model, in which all variables used to predict adoption of varieties are included in the model, ii) a restricted version of the OLS model in which many household level factors found to be jointly statistically insignificant in the unrestricted OLS model are dropped from the model; iii) an instrumental variables (IV) version of the restricted model to address potential endogeneity of adoption. The variables dropped in the restricted OLS model and the IV model include household demographic composition, education of the household head, and the value of household assets owned etc. depending on the outcome. Although some of these variables could in principle affect the outcome variable by other means than affecting adoption, the statistical results indicate that such impacts are statistically insignificant. Hence, these variables are used as instrumental variables in the IV regression.

Table 21. Impacts of adoption of modern pearl millet adoption and sorghum varieties estimated by econometric methods

Variable	**Estimation methods**	***Household level impacts***	
		Estimated impacts	***Estimated Standard Error***

Modern pearl millet varieties			
Crop yield (Kg/ha)	Simple regression	82.80**	34.32
	IV regression	157.429**	63.072
Log(Per capita total revenues – gross income (Naira))	Simple regression	0.293***	0.110
	IV regression	0.568***	0.204
Ln(Per capita value of pearl millet sale (Naira))	Simple regression	0.473	0.299
	IV regression	0.851	0.559
Ln(Per capita total value of production (Naira))	Simple regression	0.396***	0.147
	IV regression	0.700***	0.271
Ln(Per capita total wealth (Naira))	Simple regression	0.022	0.047
	IV regression	0.005	0.086
Quantity of cereals per capita (kg/person/year)	Simple regression	127.256***	28.41
	IV regression	230.507***	53.272
Number of hunger months	Simple regression	-0.172	0.107
	IV regression	-0.141	0.137
Per capita expenditure	Simple regression	-0.137	0.767
	IV regression	0.128	0.152
Modern sorghum varieties			
Crop yield (Kg/ha)	Simple regression	-33.541	31.380
	IV regression	-32.896	31.348
Log(Per capita total revenues (FCFA))	Simple regression	0.259***	0.133
	IV regression	0.250*	0.133
Ln(Per capita value of pearl millet sale (Naira))	Simple regression	0.156	0.331
	IV regression	0.153	0.323
Ln(Per capita total value of production (Naira))	Simple regression	0.214	0.167
	IV regression	0.216	0.166
Ln(Per capita total wealth (Naira))	Simple regression	0.078	0.057
	IV regression	0.233	0.185
Quantity of cereals per capita (kg/person/year)	Simple regression	5.331	31.833
	IV regression	6.111	31.283
Number of hunger months	Simple regression	0.150	0.107
	IV regression	0.089	0.087
Per capita expenditure	Simple regression	0.050	0.089
	IV regression	-0.055	0.087
*** significant at 1%, ** significant at 5% and * significant at 10%			

In each of the annexes 1 through 13, the first three regressions enable assessment of the impacts of adoption of varieties productivity, controlling for management practices and other factors. Comparing across these three regressions also allows assessment of the robustness of the conclusions to specification issues and potential endogeneity of the land management practices. These first three regressions predict the partial impact, and not the total impact, of SLM programs on productivity, since they control for the impact of land management practices, which are also influenced by these programs. The reduced form estimation enables assessment of the total impacts of adoption on the livelihood outcomes, as explained in the methodology section.

The Hansen J test of the over-identifying restrictions in the IV model indicates that the instrumental variables used in the model are valid, since the test statistic is statistically insignificant (Davidson and MacKinnon 2004). The Anderson statistic shows that the IV model is weakly identified, leading to concerns about bias in the IV model (Bound, et al. 1995).[7] The exogeneity test supports the OLS model as the preferred model, since exogeneity of the land management practices is not rejected (implying that OLS is consistent) and since OLS is more

[7] The excluded instrumental variables are strongly statistically significant predictors of all of the land management practices (p=0.0000), but the amount of variance in the land management practices explained by these instruments is relatively small (partial R^2 only 0.04 or less in all cases).

efficient (and likely less biased with weak instruments) than the IV model. The restricted OLS model is preferred over the unrestricted model, since the variables dropped are statistically insignificant and only reduce the efficiency of the model.

We find statistically insignificant impacts of most SWC measures on production in the first three regressions. Use of both organic and inorganic fertilizer has significant positive impacts on crop production, as expected. The magnitudes of these impacts are substantial, with the coefficients in the restricted OLS model implying that plots using organic fertilizer obtain 31% higher value of crop production per hectare than plots without organic fertilizer, while plots using inorganic fertilizer obtain 22% higher value of production per hectare. In a separate regression, we also included the (logarithm of the) quantity of organic and inorganic fertilizer used on plots where these inputs were used, and found that a 10% increase in inorganic fertilizer use increases the expected value of crop production by 1.4% (the amount of organic fertilizer had a statistically insignificant impact, controlling for whether organic fertilizer was used).[8] Considering the median price of NPK (the most common inorganic fertilizer used in Niger) in our study villages in 2006/07 (250 FCFA/kg) and the median level of fertilizer use on plots where fertilizer is used (20 kg/ha), a 10% increase in fertilizer use would cost 500 FCFA per hectare. The value of a resulting 1.4% increase in yield would be worth about 820 FCFA per hectare, considering that the mean value of crop yield is 58,500 FCFA/ha on plots using inorganic fertilizer. Hence the use of inorganic fertilizer appears to be marginally profitable on average, with a marginal value-cost ratio (VCR) of about 1.6 (820/500). This estimate of VCR is lower than the marginal VCR for fertilizer use estimated in a recent study of fertilizer micro-dosing in Niger (Pender, et al. 2006), in which the VCR for inorganic fertilizer was estimated to be greater than 3. This difference may be due to the broader sample frame used in the present study, which includes areas that have lower rainfall and are further from markets than in the previous study (the Pender, et al. (2006) study sampled areas near input supply shops in higher rainfall agricultural zones).

Controlling for differences in land management, we find a negative impact of PAC participation on the value of crop production. The negative impact of PAC is robust in the reduced form regression, indicating that even after allowing for the positive impacts of PAC participation on some land management practices such as stone bunds and inorganic fertilizer (and controlling for differences in other factors included in the regressions) PAC participants still obtain substantially lower value of crop production per hectare. The relatively small increments in use of stone bunds and inorganic fertilizer stimulated by participation in PAC, as estimated above, explain why the results are little different in the reduced form model. The finding of lower crop production by PAC participants is consistent with the results of the matching estimation reported in Table 4.13. The statistically insignificant impacts of other programs on crop production are also consistent with most of the impacts for the other programs reported in Table 4.13, except the positive impact estimated for PSPR using the NN method and the negative impact for PRGN using the PSM method.

Hence, we do not have robust evidence that participation in any of the programs is leading to higher value of crop production. Rather we find that the PAC program is associated with lower production. This may be because this program is also promoting activities besides crop production, possibly leading to greater income from other sources. We investigate this further below.

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[8] Regression results not reported to save space, but are available from the authors.

Unlike the matching results reported in Table 4.13, we can not investigate differences in the value of production between non-participating households in program vs. non-program villages using the regression models reported in Table 4.14, because inclusion of village fixed effects in the econometric model prevents investigation of the effects of such village level factors. In an alternative specification of the regression model, we included region level fixed effects, as well as the agroecological zone (based on ranges of length of growing period, as reported in Tables 4.1 and 4.2) and distance to the nearest town, instead of village fixed effects.[9] In this specification, we find no statistically significant difference in crop productivity between program and non-program villages, and the magnitude of the estimated impact is quite small (less than 2% impact), while the other regression results are quite similar to those reported in Table 4.14. Hence the impacts of being in a program vs. non-program village are not fully clear, with the matching estimators predicting higher productivity among non-participants in program villages than households in non-program villages, while this alternative regression predicts no significant difference.

Other factors found to have significant impacts on crop production include the number of women in the household (negative (-) impact in the unrestricted OLS and reduced form models), the area of land owned by the household (- in all regressions), the value of livestock owned (+), plot size (-), soil fertility of the plot (+ for very good compared to poor), soil texture of the plot (- for sandy/clay and + for loam, compared to sandy soil), and means of plot acquisition (+ for rented plots and plots acquired by land pawning arrangements, compared to inherited plots). We will not comment in detail on these findings since our focus is on the impacts of SLM programs. However, we note that some of these findings are consistent with many other studies of determinants of crop production in sub-Saharan Africa and other developing regions. For example, the inverse relationship between farm size and productivity has been found in many studies (e.g., Sen 1975; Berry and Cline 1979; Carter 1984, Barrett 1996; Bhalla 1998; Heltberg 1998; Lamb 2003; Nkonya, et al. 2004; and Pender, et al. 2004), as has the positive impact of livestock on productivity. The positive impact of land rental on productivity is also consistent with several studies, and suggests that tenants acquire land because they can use it more productively than their owners due to surplus of complementary production factors such as labor (Binswanger and Rosenzweig 1986). Higher productivity by tenants also may be necessary to cover the transaction costs of leasing arrangements (Pender and Fafchamps 2006). The negative impact of the number of women in the household is not a general finding in other studies, but suggests that women are more focused on other livelihood activities and less on crop production.

The estimated determinants of household income per capita are reported in Table 4.15. In this table, we report results of three regressions: i) unrestricted OLS (including program participation and all explanatory variables used in Table 4.8); ii) restricted OLS, dropping the variables reflecting the social status of the household head (which are jointly insignificant in the unrestricted model); and iii) IV estimation, treating program participation variables as endogenous. The social status variables are used as instrumental variables. We also use the household endowments in 2000/01 of land, land quality, other assets, education, family composition, and migrants as instrumental variables (the levels of these variables in 2006/07 are used as explanatory variables in the regression). As shown by the statistical tests reported in Table 4.15, the instrumental variables used are valid (insignificant Sargan test) and exogeneity of the program participation variables is supported (insignificant C exogeneity test). However,

[9] Regression not reported to save space, but is available from the authors.

weak identification is again a problem in this IV model (insignificant Anderson statistic). The restricted OLS model is therefore the preferred model.

We find statistically insignificant impacts of participation in most SLM programs on income in the regressions, except a weakly significant (at 10% level) negative coefficient of PAC participation in the OLS models and a very large positive impact of PSPR only in the IV model. The negative coefficients for PAC suggest that the lower value of crop production by PAC participants found using both matching and econometric methods is leading to lower income, and is not fully compensated by higher income from other sources. These negative impacts might be near term effects due to investments and changes in activities being undertaken by PAC participants that are reducing their income in the near term. Such investments may take some time to result in increased incomes; hence it may be too soon to observe positive impacts of PAC, which is a relatively recent program. The positive impact of PSPR estimated in the IV regression is not robust in the OLS models or in the matching results, and may be subject to bias due to weak identification of the IV model, as noted previously.

For other programs, the coefficients of program participation are quite small in the OLS models (implying income impacts of less than 7%) and are not statistically significant. These insignificant income impacts of program participation are consistent with the findings of the matching estimators reported in Table 4.13. Hence we do not have robust statistical evidence of a positive impact of participation in any SLM programs on household income per capita.

As for the value of crop production, we investigated the difference in income between households in non-program villages and non-participants in program villages by estimating an alternative specification of the regression model including region fixed effects, the agroecological zone, and distance to nearest town, rather than village fixed effects.[10] We find that the mean difference in income between non-program households in program villages and households in non-program villages is quantitively small (about 2%) and statistically insignificant. None of the program participation variables is even weakly statistically significant in this alternative specification, while the variables found to have a significant impact on income in Table 4.15 are also significant in this specification with a similar estimated magnitude of impact. Hence, we do not have evidence from these regressions of positive income impacts of program placement or participation in programs. These findings contrast with the findings using matching estimators reported in Table 4.13, which showed a positive and statistically significant impact of program presence on income using the NN estimator. Given the lack of robustness of these results, we judge the evidence to be inconclusive concerning the impacts of village level presence of SLM programs on household incomes.

Other factors that are found to have a significant impact on household income per capita in Table 4.15 include education of the household head (positive and weakly significant for secondary education), the dependency ratio (-), the number of men and women in the household (-), the number of male migrants (+), the value of livestock (+), the value of household assets (+), and the share of land acquired through purchase (+ but weakly significant in the preferred OLS model). The positive impacts of education and livestock ownership on income and the negative impact of the dependency ratio are consistent with our expectations and with numerous other studies in developing countries. The negative impact of the number of adult men and women in the household on *per capita* income indicates that increased labor supply does not lead to a

[10] Regression results not reported to save space, but are available from the authors.

proportionate increase in income, suggesting decreasing returns to scale in household size (Pender 1998). Both this result and the negative impact of the dependency ratio demonstrate the importance of reducing demographic pressure in order to address poverty in rural Niger. The positive impact of male migrants on income demonstrates the importance of alternative sources of livelihood in addressing poverty in rural Niger. The positive associations between household assets and land purchases and income may reflect reverse causality; i.e., households capable of earning more income are more able to purchase household assets and land. The fact that we did not find a positive impact of either household assets or land purchasing on crop production makes such a reverse causality explanation more plausible, since it is not clear how purchasing household assets or land causes increased income.

The fact that land ownership and land quality are not statistically significant determinants of income, together with the insignificant impacts of SLM programs on income, suggests that the potential to reduce poverty through investments in improved land management may be limited, at least in the near term. However, we should not ignore the positive impacts that we have found (e.g., the positive impact of zai and organic and inorganic fertilizer on crop production and the impact of several SLM programs on use of these practices). It may be that such impacts are not large enough to have a major impact on the total level of household income, but they still should be taken into consideration when assessing the benefits and costs of SLM program investments. Furthermore, SLM programs may also have impacts on household income by improving management of communal lands (e.g., by improving the availability of fodder, timber, fuel wood and other valuable goods and services). And such programs may have beneficial social and environmental impacts that are not fully reflected in current household income (though they may influence changes in production and income in the future). We address these issues to the extent possible based on our household and village survey data in subsequent sections.

5.8. Impacts on poorer versus wealthier households

To investigate whether the impacts of adoption of improved pearl millet or sorghum varieties vary by the wealth status of households, we estimated the productivity and income regressions separately for the first quarter, second, third and fourth quarter of the sample, based on the estimated total value of assets (land, livestock, farm equipment, household assets) owned by households.[11] The results for value of crop production are reported in Table 4.16. We find that use of organic fertilizer has a statistically significant positive impact on crop production (and similar in magnitude) for both the poorer and wealthier households. By contrast, we find a significant positive impact of inorganic fertilizer only for the wealthier households. Apparently other complementary assets are important for farmers to be able to use inorganic fertilizer most productively. Mulching has a weakly statistically significant positive impact (at 10% level) on productivity of the wealthier households. None of the other land management practices has a statistically significant impact on production for either the poorer or the wealthier sub-sample.

[11] We also investigated impacts for the poorest vs. the richest half of the sample using the matching estimators. However, in many cases these models were not estimable for the sub-samples. This is because partitioning the sample into smaller units (e.g., poorer vs. richer PAC vs. non-PAC households in PAC villages) resulted in small samples for comparisons in many cases, compounded by the use of probit models with many dummy explanatory variables to estimate propensity scores (which drop observations if dummy explanatory variables perfectly predict the program status) and the common support requirement used in the matching procedures (which further drops observations). Hence we do not report matching results for the sub-sample of poorer vs. richer households in this subsection, or for analyses of other sub-samples evaluated in following subsections (i.e., estimated impacts by region and agroecological zone).

Participation in PAC has a significant negative impact on crop production only for the wealthier households. Perhaps such households are more prone to invest in non-agricultural activities through involvement in PAC, with negative implications for crop production. Participation in other government programs has a weakly statistically significant positive impact on production by poorer households in both the full and reduced form models.

The estimated impacts of program participation on incomes of poorer vs. wealthier households are shown in Table 4.17. We find no statistically significant impacts of participation in any programs on incomes of either group. With respect to poorer households, NGO programs have the most favorable estimated impact (about 25% higher estimated income for participants), though this impact is not statistically significant due to the high variance of estimated impacts.

Table 22. PSM matching results (NN) of adoption of pearl millet and sorghum based on wealth groups

Pearl millet producers	**Coefficient**	**Standard Deviation**
Average household yield		
Less 318,432.5 Naira (1st quarter)	251.967***	101.591 (2.48)
Between 318,432.and 776,193.5 Naira (2nd quarter)	76.67	104.857 (0.73)
Between 776,193.5 and 1,500,535 Naira (3rd quarter)	67.519	85.802 (0.79)
More than 1,500,535 Naira (4th quarter)	106.752	110.350 (0.97)
Log of total value of production		
Less 318,432.5 Naira (1st quarter)	0.917**	0.539
Between 318,432.and 776,193.5 Naira (2nd quarter)	0.594	0.344
Between 776,193.5 and 1,500,535 Naira (3rd quarter)	0.287	0.587
More than 1,500,535 Naira (4th quarter)	0.495	0.386
Log of per capita expenditures		
Less 318,432.5 Naira (1st quarter)	0.315	0.220
Between 318,432.and 776,193.5 Naira (2nd quarter)	0.344	0.268
Between 776,193.5 and 1,500,535 Naira (3rd quarter)	0.217	0.351
More than 1,500,535 Naira (4th quarter)	-0.009	0.239
Sorghum producers		
Household average yield		
Less 285,762 Naira (1st quarter)	-112.507	103.512 (-1.09)
Between 285,762 and 686,744 Naira (2nd quarter)	-36.496	125.543 (-0.29)
Between 686,744 and 1,455,532Naira (3rd quarter)	-125.575	80.062 (-1.57)
More than 1,455,532Naira (4th quarter)	86.527	102.323 (0.85)
Log of total value of production		
Less 285,762 Naira (1st quarter)	1.021	0.663 (1.54)
Between 285,762 and 686,744 Naira (2nd quarter)	0.666	0.467 (1.43)
Between 686,744 and 1,455,532Naira (3rd quarter)	0.086	0.452 (0.19)
More than 1,455,532Naira (4th quarter)	-0.408	0.391 (-1.04)
Log of per capita expenditures		
Less 285,762 Naira (1st quarter)	-0.313	0.169 (-0.52)
Between 285,762 and 686,744 Naira (2nd quarter)	-0.180	0.243 (-0.74)
Between 686,744 and 1,455,532Naira (3rd quarter)	0.773	0.404(1.91)
More than 1,455,532Naira (4th quarter)	0.263	0.303 (0.87)

To investigate whether the impacts of improved sorghum or pearl millet varieties vary according to the wealth status of households, regressions were estimated separately for the poorer and wealthier half of the sample.

Economic Benefits of modern pearl millet varieties[12]
An economic surplus model (Alston et al., 1995) is used to derive summary measures of the impacts of pearl millet improvement under certain reasonable assumptions for research and development starting in 1996 and benefits accruing from 1999 (beginning of adoption of improved technologies) to 2009. The benefits were measured based on a parallel downward shift in the (linear) supply curve following research. The annual flows of gross economic benefits from pearl millet are estimated with the benefits finally discounted to derive the present value (in 2009) of total net benefits from the research and development. The key parameters that determine the magnitude of the economic benefits are: (1) calculated in terms of area under modern pearl millet varieties; (2) yield gains following adoption; and (3) research levels of production and prices.

Specifically, the economic surplus empirical model for an open economy was used to calculate the economic gross benefits from a downward shift in the supply curve. In an open economy, economic surplus measures can be derived using formulas presented in Alston et al. (1995)—i.e. change in economic Surplus

$$\Delta ES = P_0 Q_0 K_t (1 + 0.5 K_t \epsilon)$$

where K_t is the supply shift representing cost reduction per ton of output as a proportion of product price (P); P_0 represents the FAO price for 2006─2008 (US$/ton); Q_0 is research level of production for 2006─2008; and ε is the price elasticity of supply. The research-induced supply shift parameter, K, is the single most important parameter influencing total economic surplus results from unit cost reductions and was derived as $K_t = A_t\ (\Delta Y/Y)/\varepsilon$ where $\Delta Y/Y$ is the average proportional yield increase per hectare, with the elasticity of supply (ε) used to convert the gross production effect of research-induced yield changes to a gross unit production cost effect.

Annual supply shifts were then computed based on adoption profile for improved pearl millet (A_t) for the period from 1999 to 2009 for release starting in 1996 in Nigeria. Adoption (A_t) is assumed to follow the logistic diffusion curve starting in 1999 with less than 1% of the area put under improved technologies in 2001. Table 1 presents the values of technology-, and market-related parameters used in computing the impacts of pearl millet research and extension in Northern Nigeria. The values of these parameters and others were assembled from several sources—such as project proposal, past empirical work (e.g. Alston et al. 1995; Macaver, 2002), and others (e.g. FAOSTAT).

Table 23: Values of key parameters used in the projection of impacts of pearl millet research and extension in Nigeria

Parameter	***Value***
Productivity change (%)	9.1142
Maximum potential adoption (%)	59%
Gestation lag (years until start of adoption)	3
Adoption lag (years until current maximum adoption)	11
Adoption lag (years until potential adoption)	25
Elasticity of supply (unitary elastic)	1.0

[12] Data is not yet available on research and development costs. This is because of insufficient knowledge of the R4D process that should be used to identify research and development costs.

Elasticity of demand	Perfectly elastic
Discount rate (%)	25
Year of release	1996
Year research started	1988
Time path of benefits from investments	1996-2009

The summary measures of the discounted gross benefits millet research is estimated to US US$8,833,216.

5.9. Discussions on impacts of adoption of pearl millet and sorghum varieties

The impacts of adoption of pearl millet and sorghum varieties on poverty and food security should be interpreted in consideration with access to business development services offered by the public and private sector as well as the policy and institutional environment that govern the sorghum and pearl millet value chains. Input supply as especially seed of improved varieties is limited. Since 1996, after ICRISAT left Nigeria, none of the institutions was responsible for variety maintenance. Therefore, seed production and access to seed.

Table 24. Main source of pearl millet and sorghum varieties seed planted in 2008-09

	Pearl millet			*Sorghum*		
Source	*Improved varieties*	*Local varieties*	*All pearl millet varieties*	*Improved varieties*	*Local varieties*	*All sorghum varieties*
On-farm trials	2.42	4.39	3.82	2.49	5.16	4.07
Another farmer	7.25	11.49	10.24	15.98	10.47	12.82
Relative	2.42	11.99	9.11	15.35	9.04	12.61
Own saved seed	58.46	67.57	65.92	60.37	63.99	64.60
Grain trader	0.44	0.84	0.67	2.07	0.57	1.32
IAR	0.00	0.17	0.11	0.00	0.14	0.10
ICRISAT	0.22	0.17	0.22	0.00	0.00	0.00
NGOs	1.10	0.51	0.56	0.41	0.43	0.51
ADPs	27.91	4.39	15.86	3.32	14.49	10.78
Seed companies	0.00	0.00	0.00	0.21	0.00	0.10
Others (specify)	0.66	0.34	0.56	0.21	0.29	0.20

Source : Impacts of Sorghum and Pearl Millet Varieties in Northern Nigeria survey, 2008-10

FAO yield data.
Abnormal months (drier months). Gains from early maturing varieties.

VI. Conclusions and implications

The report used the treatment effect estimation framework to estimate the adoption of sorghum and pearl millet and their determinants. The current adoption of rate of modern pearl millet varieties is estimated to 35% whereas the probability of adoption in the population is estimated to 59% leaving and adoption gap of 24%. In the case of sorghum, the current adoption rate is estimated to 23% of sorghum producers against the population adoption rate of about 28% leaving adoption gap of only 4%. While increased awareness or promotion of SOSAT-C88 is likely to bring more adoption, promotion of sorghum varieties will not necessary increase a lot from the current level of adoption.

The propensity score matching and econometric estimates were used to estimate the impacts of modern varieties. All five estimation methods show a positive impact pearl millet adoption on yield and per capita cereal production above 95% significance level. Impacts on the natural log of total revenues, value of pearl millet sale, total value of production and total wealth

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References

Abadie, A., and G.W. Imbens. 2006a. Large sample properties of matching estimators for average treatment effects. *Econometrica* 74 (1): 235–267.

Abadie, A., and G.W. Imbens. 2006b. On the failure of bootstrapping for matching estimators. Unpublished manuscript. John F. Kennedy School of Government, Harvard University, http://www.ksg.harvard.edu/fs/aabadie/

Abadie, A., D. Drukker, J. Leber Herr, and G.W. Imbens. 2004. Implementing matching estimators for average treatment effects in Stata. *Stata Journal*, vol. 4(3), 290-311.

Adesina, Akinwumi A., and Jojo Baidu-Forson. 1995. "Farmers' Perceptions and Adoption of New Agricultural Technology: Evidence from Analysis in Burkina Faso and Guinea, West Africa." Agricultural Economics 13, no. 1: 1– 9.

Adesina, Akinwumi A., and Moses M. Zinnah. 1993. "Technology Characteristics, Farmers' Perceptions and Adoption Decisions: A Tobit Model Application in Sierra Leone." Agricultural Economics 9, no. 4: 297–311.

Adesina, Akinwumi A., and Sirajo Seidi. 1995. "Farmers' Perceptions and Adoption of New Agricultural Technology: Analysis of Modern Mangrove Rice Varieties in Guinea Bissau." Quarterly Journal of International Agriculture 34, no. 4: 358–71.

Akinleye & MAY Rahji (2007) Nutrient elasticities among Nigerian Households differentiated by income, Agrekon, Vol. 46 (2):274-288.

Anogie, D.A., Z.G.S. Turaki, U.C. Undiandeye, J Umar, B.A. Baba and A.G. Adam. 2009. Studies into the Constraints to Cereals Production in the North-East zone, Nigeria. Research Report. Lake Chad Research Institute (LCRI), Federal Ministry of Agriculture & Water Resources, Nigeria.

Baum, C. F., M. E. Schaffer, and S. Stillman. 2003. Instrumental variables and GMM: estimation and testing. Unpublished working paper no. 545, Boston College Department of Economics. http://fmwww.bc.edu/ec-p/WP545.pdf.

Binswanger, H.P. and J. von Braun. 1991. Technological change and commercialization in agriculture. The effect on the poor. *The World Bank Research Observer* 6(1):57-80.

Bound, J., D.A. Jaeger, and R.M. Baker. 1995. Problems with instrumental variables estimation when the correlation between the instruments and the exogenous explanatory variable is weak. *Journal of the American Statistical Association* 90, 443-450.

CIMMYT, 1988. *From agronomic data to farmer recommendation: An economics training manual*. Completely revised edition. Mexico DF.

Davidson, R. and J.G. MacKinnon. 2004. *Econometric Theory and Methods*. Oxford: Oxford University Press.

de Janvry, A. and E. Sadoulet. 2001. World poverty and ythe role of agricultural technology. Directs and indirect effects. *Journal of Development Studies*. 38(4):1-26.

Diagne, A. 2006. Diffusion and Adoption of NERICA rice varieties in Cote d'Ivoire. *The Developing Economies*, XLIV-2 (June 2006):208-230.

Feder, G., Just, R. E. and D. Zilberman 1985. Adoption of agricultural innovations in developing countries: a survey. *Econ. Dev. Cult. Ch*ange 33(2), 255–295.

Gupta, S.C., A.O. Ogungbile, I Angarawai, I.E. Izeaky and S.E. Alaldele. Farmers' participatory selection of sorghum and pearl millet varieties in Nigeria. p. 232-242. *In* Akintayo, I. and Sedgo, J. (ed.). 2001. Towards sustainable sorghum production, utilization, and commercialization in West and Central Africa: proceedings of a Technical Workshop of the West and Central Africa Sorghum Research Network, 19-22 April 1999, Lome, Togo. Bamako, BP 320, Mali: West and Central Africa Sorghum Research Network; and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. pages. ISBN 92-9066-4330-9. Order code CPE131.

Heckman, J., H Ichimura, J Smith, and P Todd (1988).Characterizing selection bias using experimental data.*Econometrica*, 66:1017–99, 1988.

ICRISAT (Institut international de recherche sur les cultures des zones tropicales semi-arides) Centre Sahélien. 1990. Programme ouest africain de l'ICRISAT, Rapport annuel 1988. B.P. 12404, Niamey, Niger : ICRISAT Centre Sahélien.

ICRISAT (Institut international de recherche sur les cultures des zones tropicales semi-arides) Centre Sahélien. 1992. Programme ouest africain de l'ICRISAT, Rapport annuel 1990. B.P. 12404, Niamey, Niger : ICRISAT Centre Sahélien.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Sahelian Center. 1993. ICRISAT West African Programs Annual Report 1992. B.P. 12404, Niamey, Niger : ICRISAT Sahelian Center.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Sahelian Center. 1992. ICRISAT West African Programs Annual Report 1991. B.P. 12404, Niamey, Niger: ICRISAT Sahelian Center.

Just R E. and D. Zilbermann. 1988. The effects of agricultural development policies on income distribution and technological change in agriculture. *Journal of Development Economics*, 20(2):193-216.

Macaver, O.J. (2002). Economic Impact Assessment of Public Investments in Sorghum Research and extension in katsina state, Nigeria. PhD thesis, Department of Agricultural Economics and Rural Sociology, Ahmadu Bello University, 2002.

Maddala, G.S. 1983. *Limited-Dependent and Qualitative Variables in Econometrics*. Econometric Society Monographs No. 3. Cambridge: Cambridge University Press.

Mas-Colell, A., Whinston, M.D., Green, J.R., 1995. *Microeconomic Theory*. New York, Oxford University Press.

Mukherjee, C., H. White and M. Wuyts, 1998. *Econometrics and data analysis for developing countries.* London: Routledge.

Ndjeunga J and Bantilan MCS. 2005. Uptake of improved technologies in the semi-arid tropics of West Africa: Why is agricultural transformation lagging behind? eJADE 2(1):85–102.

Ogungbile, A.G., Tabo, R. and S.A. Rahman 2002. Factors affecting adoption of ICSV111 and ICSV400 sorghum varieties in the Guinea and Sudan savanna of Nigeria. The Plant Scientist Volume 3:21-32, 2002.

Oloko, O.A., Oyekan, P.O. and R.I. Mani. (2000). Recents accomplishments of the National agricultural research institutes. Agricultural Science Department, Federal Ministry of Agriculture and Rural Development, Garki-Abuja.

Ravallion, M. 2005. Evaluating anti-poverty programs. World Bank Policy Research Working Paper 3625. The World Bank, Washington, D.C.

Rosenbaum, P.R. and D. B. Rubin (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, 70(1):41–55, 1983.

Yapi AM, Debrah SK, Dehala G and Ndjomaha C. 1999a. Impact of germplasm research spillovers: the case of sorghum variety S 35 in Cameroon and Chad. Impact Series no.3. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 30 pp.

Yapi AM, Dehala G, Ngawara K and Issaka A. 1999b. Assessment of the economic impact of sorghum variety S 35 in Chad. Impact Series no. 6. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 34 pp.

Yapi AM, Kergna AO, Debrah SK, Sidibe A and Sanogo O. 1998. Impact of sorghum and millet research in Mali. Pages 76–93 in Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2–4 Dec 1996, ICRISAT, Patancheru, India (Bantilan MCS and Joshi PK, eds.) Patancheru 502 324, Andhra Pradesh, India: International Crop Research Institute for the Semi-Arid Tropics.

Yapi AM, Kergna AO, Debrah SK, Sidibe A and Sanogo O. 2000. Analysis of the economic impact of sorghum and millet research in Mali. Impact Series No 8. Patancheru 502 324, Andrha Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 60 pp.

Annex 1. OLS and IV regression results on average household pearl millet yield for pearl millet producers

	olsyield		ols_reducedyield		ivyld		ivexogyld	
	coef	se	coef	se	coef	se	coef	se
advarameltot1	66.868	40.725	70.114*	40.545	481.221	457.770	70.114*	38.288
housiz08	3.892	3.958						
adequiv08	35.046	27.727						
depratio08	-15.655	13.201						
age0809	-1.507	1.572						
Total number of household's members educated in 2008	0.713	4.701						
lnvaltoteq08	-5.111	6.766	-4.495	6.692	-5.047	6.716	-4.495	6.320
lnvalbetail08	8.993**	4.087	9.618**	4.042	8.224*	4.326	9.618**	3.817
lnvalbien08	4.498	4.571	4.181	4.546	5.625	4.817	4.181	4.293
totown08	-5.063*	2.719	-4.811*	2.665	-4.280	2.728	-4.811*	2.517
avefert08	-20.505	60.152	-12.427	59.782	-26.326	61.702	-12.427	56.454
goofert08	-111.312***	41.744	-109.435***	41.476	-110.696***	41.474	-109.435***	39.168
vgofert08	-37.728	42.103	-35.555	41.876	-58.523	48.994	-35.555	39.545
inherita08	48.109	59.466	52.795	59.319	40.560	60.816	52.795	56.017
rent08	9.038	83.101	21.399	82.734	-37.537	105.401	21.399	78.129
collat08	186.242	258.462	150.440	257.546	117.190	260.015	150.440	243.211
purcha08	44.196	42.228	47.800	41.817	36.885	43.509	47.800	39.489
sandy	-44.843	42.190	-47.025	42.079	-42.752	42.319	-47.025	39.737
clay	-70.450	44.952	-71.467	44.879	-66.906	45.135	-71.467*	42.381
sandclay	138.517***	40.177	136.014***	40.077	130.031***	40.598	136.014***	37.846
loamy	62.947	43.902	66.432	43.777	39.810	52.782	66.432	41.341
fagrpromar	78.921**	35.762	75.817**	35.539	89.970**	38.832	75.817**	33.561
fcerdit	-43.140	43.447	-43.616	43.393	-40.997	43.464	-43.616	40.978
fagrproduc	0.224	19.735	-0.368	19.625	-5.063	20.293	-0.368	18.533
mothergroup	32.457	21.168	34.286	21.075	20.009	26.351	34.286*	19.902
nrainfall==2	308.678	269.532	291.907	267.969	-234.390	280.049	-137.652	244.433
nrainfall==3	72.014	255.118	93.189	252.930	-519.178	318.586	-336.369	232.201
nrainfall==4	61.792	207.199	71.559	206.297	-532.817*	275.153	-358.000*	184.474
nrainfall==5	308.234	237.508	318.026	236.529	-210.498	251.896	-111.533	214.236
_cons	538.180**	226.859	536.765**	213.154	994.520***	190.224	966.324***	177.301
Number of observations	961		961		961		961	
Adjusted R2	0.260		0.261		0.173		0.261	
F test od significance of variables dropped from restricted OLS and IV models	0.83 (p.=0.5296)							
Hansen's J test of over-identifying restrictions					3.338 (p=0.5030)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					7.529 (p=0.1842)			
Exogeneity (C) test in reduced model							0.910 9p=0.340)	
note: *** p<0.01, ** p<0.05, * p<0.1								

Coefficients of local government fixed effect not reported to save space.

Annex 2. OLS and IV regression results on the per capita total value of production for pearl millet producers

	olstvp		ols_reducedtvp		ivtvp		ivexogtvp	
	coef	se	coef	se	coef	se	coef	se
advarameltot1	0.690***	0.153	0.709***	0.153	3.970*	2.309	0.709***	0.145
housiz08	-0.002	0.015						
adequiv08	-0.471***	0.104	-0.481***	0.103	-0.619***	0.154	-0.481***	0.098
depratio08	-0.009	0.049						
age0809	0.001	0.006						
otal number of household's members ducated in 2008	0.028	0.018						
nvaltoteq08	0.035	0.026						
nvalbetail08	0.068***	0.015	0.072***	0.015	0.056***	0.021	0.072***	0.014
nvalbien08	0.058***	0.017	0.057***	0.017	0.068***	0.022	0.057***	0.016
totown08	0.011	0.010	0.015	0.010	0.017	0.012	0.015	0.010
avefert08	-0.488**	0.232	-0.516**	0.232	-0.592**	0.273	-0.516**	0.220
goofert08	0.131	0.157	0.125	0.157	0.152	0.183	0.125	0.149
vgofert08	0.172	0.159	0.166	0.159	-0.029	0.229	0.166	0.150
inherita08	0.095	0.218	0.125	0.217	0.107	0.251	0.125	0.206
rent08	0.010	0.320	-0.030	0.318	-0.370	0.439	-0.030	0.301
collat08	0.694	1.015	0.686	1.012	0.367	1.190	0.686	0.959
purcha08	0.350**	0.160	0.380**	0.159	0.330*	0.187	0.380**	0.150
sandy	-0.197	0.158	-0.189	0.158	-0.213	0.184	-0.189	0.150
clay	0.052	0.171	0.057	0.171	0.115	0.202	0.057	0.162
sandclay	0.231	0.150	0.238	0.150	0.171	0.180	0.238*	0.142
loamy	0.319**	0.162	0.333**	0.162	0.109	0.245	0.333**	0.153
fagrpromar	0.232*	0.140	0.230*	0.139	0.327*	0.175	0.230*	0.132
fcerdit	0.025	0.171	0.016	0.170	0.021	0.197	0.016	0.162
fagrproduc	-0.124	0.077	-0.119	0.077	-0.172*	0.096	-0.119	0.073
mothergroup	-0.161**	0.080	-0.167**	0.080	-0.267**	0.116	-0.167**	0.076
cons	9.059***	0.708	9.518***	0.612	8.571***	0.974	9.518***	0.580
Number of observations	1,044		1,044		1,044		1,044	
djusted R2	0.373		0.373		0.068		0.373	
F test od significance of variables dropped from restricted OLS and IV models	1.01 (p=0.409)							
Hansen's J test of over-identifying restrictions					1.786 (p=0.7751)			
Anderson canonical correlation LR statistic in IV model (test for IV model under-identification)					6.099 (p=0.2967)			
Exogeneity (C) test in reduced model					2.981 (p=0.0843)			
note: *** p<0.01, ** p<0.05, * p<0.1								

Annex 3 . OLS and IV regression results on the per capita total household wealth of pearl millet producers

	olswealth		ols_reducedwealth		ivwealth		ivexogwealth	
	coef	se	coef	se	coef	se	coef	se
advarameltot1	0.022	0.082	0.016	0.082	-1.120	1.189	0.016	0.078
housiz08	0.036***	0.008	0.035***	0.008	0.040***	0.009	0.035***	0.007
adequiv08	-0.455***	0.055	-0.449***	0.055	-0.403***	0.075	-0.449***	0.052
depratio08	-0.011	0.026	-0.010	0.026	-0.006	0.028	-0.010	0.025
age0809	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003
Total number of household's members educated in 2008	0.004	0.010	0.004	0.010	0.009	0.011	0.004	0.009
totown08	0.022***	0.005	0.023***	0.005	0.021***	0.006	0.023***	0.005
avefert08	-0.017	0.124	-0.027	0.124	0.014	0.136	-0.027	0.117
goofert08	-0.133	0.084	-0.143*	0.083	-0.154*	0.087	-0.143*	0.079
vgofert08	0.104	0.085	0.103	0.085	0.173	0.115	0.103	0.081
inherita08	0.194*	0.116	0.191*	0.115	0.192	0.120	0.191*	0.110
rent08	-0.140	0.171	-0.147	0.170	-0.017	0.223	-0.147	0.161
collat08	0.202	0.543	0.214	0.542	0.329	0.578	0.214	0.515
purcha08	0.210**	0.086	0.215**	0.085	0.221**	0.089	0.215***	0.081
sandy	0.034	0.085	0.031	0.085	0.045	0.089	0.031	0.080
clay	-0.157*	0.091	-0.156*	0.091	-0.182*	0.099	-0.156*	0.086
sandclay	0.031	0.080	0.035	0.080	0.057	0.087	0.035	0.076
loamy	-0.081	0.087	-0.081	0.087	-0.010	0.117	-0.081	0.082
fagrpromar	0.010	0.075						
fcerdit	-0.063	0.091						
fagrproduc	-0.016	0.041						
mothergroup	-0.043	0.043						
_cons	13.233***	0.340	13.223***	0.339	13.471***	0.437	13.223***	0.322
Number of observations	1,044		1,044		1,044		1,044	
Adjusted R2	0.268		0.269		0.119		0.269	
F test od significance of variables dropped from restricted OLS and IV models	0.46 (p=0.7864)							
Hansen's J test of over-identifying restrictions					0.763 (p=0.8584)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					5.358 (0.2525)			
Exogeneity (C) test in reduced model					1.109 (0.2923)			

note: *** p<0.01, ** p<0.05, * p<0.1

Annex 4. OLS and IV regression results on the per capita pearl millet sale by of pearl millet producers

	olsvente		ols_reducedvente		ivvente		ivexogvente	
	coef	se	coef	se	coef	se	coef	se
advarameltot1	0.544**	0.270	0.516*	0.268	-2.264	2.705	0.516**	0.254
housiz08	0.012	0.026						
adequiv08	-0.119	0.183						
depratio08	0.095	0.087						
age0809	-0.011	0.011						
Total number of household's members educated in 2008	-0.024	0.031						
lnvaltoteq08	0.076*	0.046	0.077*	0.045	0.080*	0.045	0.077*	0.043
lnvalbetail08	0.003	0.026	-0.002	0.026	0.011	0.029	-0.002	0.024
totown08	0.049***	0.018	0.049***	0.018	0.047***	0.018	0.049***	0.017
cellular081	0.118	0.246	0.172	0.243	0.167	0.243	0.172	0.230
radio081	0.108	0.281	0.118	0.280	0.332	0.348	0.118	0.265
television081	-0.737*	0.396	-0.661*	0.390	-0.452	0.439	-0.661*	0.370
avefert08	0.129	0.408	0.092	0.406	0.190	0.417	0.092	0.385
goofert08	-0.317	0.277	-0.325	0.276	-0.338	0.276	-0.325	0.261
vgofert08	0.653**	0.279	0.696**	0.278	0.848***	0.315	0.696***	0.263
inherita08	-0.338	0.381	-0.349	0.380	-0.322	0.381	-0.349	0.360
rent08	0.181	0.560	0.213	0.557	0.478	0.613	0.213	0.528
collat08	-0.390	1.779	-0.237	1.773	-0.005	1.786	-0.237	1.678
purcha08	0.360	0.282	0.339	0.279	0.366	0.280	0.339	0.264
sandy	-0.368	0.278	-0.355	0.277	-0.336	0.278	-0.355	0.263
clay	-0.550*	0.300	-0.544*	0.299	-0.600**	0.304	-0.544*	0.283
sandclay	-0.071	0.264	-0.065	0.263	-0.026	0.266	-0.065	0.249
loamy	0.023	0.285	-0.013	0.284	0.197	0.349	-0.013	0.269
fagrpromar	0.170	0.245	0.140	0.243	0.062	0.255	0.140	0.231
fcerdit	0.012	0.298	0.007	0.298	-0.005	0.298	0.007	0.282
fagrproduc	0.079	0.135	0.091	0.135	0.127	0.139	0.091	0.127
mothergroup	-0.277**	0.141	-0.257*	0.140	-0.179	0.159	-0.257*	0.133
_cons	0.123	1.226	-0.419	1.086	0.310	1.295	-0.419	1.028
Number of observations	1,044		1,044		1,044		1,044	
Adjusted R2	0.481		0.481		0.422		0.481	
F test od significance of variables dropped from restricted OLS and IV models	0.73 (p=0.6014)							
Hansen's J test of over-identifying restrictions					2.587(p=0.6291)			
Anderson canonical correlation LR statistic in IV model (test for IV model under-identification)					10.245 (p=0.0686)			
Exogeneity (C) test in reduced model							1.190 (p=0.2754)	

note: *** p<0.01, ** p<0.05, * p<0.1

Annex 5. OLS and IV regression results on per capita cereal availability of pearl millet producers

	olscapi1		ols_reducedcapi1		ivcapi1		ivexogcapi1	
	coef	se	coef	se	coef	se	coef	se
advarameltot1	134.172***	30.881	130.789***	30.787	-494.860	477.179	130.789***	29.151
housiz08	-30.669***	3.015	-30.978***	3.001	-28.805***	3.791	-30.978***	2.841
adequiv08	-52.170**	20.989	-51.802**	20.902	-28.430	29.674	-51.802***	19.791
depratio08	-1.985	9.932	-2.773	9.908	-0.856	11.356	-2.773	9.381
age0809	0.544	1.209	0.757	1.202	1.223	1.412	0.757	1.138
Total number of household's members educated in 2008	4.770	3.586	4.775	3.577	7.255	4.483	4.775	3.387
lnvaltoteq08	13.303**	5.216	13.394**	5.212	14.097**	5.948	13.394***	4.935
lnvalbetail08	6.540**	3.025	6.399**	2.997	8.800**	3.865	6.399**	2.837
lnvalbien08	1.411	3.499	1.356	3.488	-0.660	4.252	1.356	3.303
lnreven08	-3.839	2.721	-3.715	2.718	-3.182	3.116	-3.715	2.574
totown08	6.895***	2.072	6.991***	2.069	6.005**	2.469	6.991***	1.959
avefert08	-28.538	46.790	-33.419	46.567	-11.556	55.485	-33.419	44.093
goofert08	10.889	31.838	8.805	31.464	4.100	35.945	8.805	29.792
vgofert08	59.134*	32.117	62.625*	32.013	100.021**	46.188	62.625**	30.312
inherita08	-9.605	43.993	-7.790	43.801	-6.343	49.802	-7.790	41.474
rent08	101.004	64.547	96.016	64.355	170.525*	92.539	96.016	60.936
collat08	-89.267	204.525	-85.571	204.299	-22.317	237.162	-85.571	193.443
purcha08	44.857	32.364	45.090	32.298	47.458	36.758	45.090	30.582
sandy	-61.067*	31.963	-62.134*	31.920	-55.980	36.585	-62.134**	30.224
clay	-53.326	34.454	-49.539	34.246	-62.099	40.083	-49.539	32.426
sandclay	9.105	30.378	8.318	30.341	20.218	35.657	8.318	28.728
loamy	64.662**	32.688	64.817**	32.645	105.291**	48.217	64.817**	30.911
fagrpromar	45.005	28.176						
fcerdit	-3.529	34.384						
fagrproduc	-9.713	15.525						
mothergroup	-12.088	16.198						
_cons	286.415**	143.159	278.761*	142.700	407.479**	189.468	278.761**	135.118
Number of observations	1,044		1,044		1,044		1,044	
Adjusted R2	0.345		0.346		0.057		0.346	
F test od significance of variables dropped from restricted OLS and IV models	0.84 (p=0.503)							
Hansen's J test of over-identifying restrictions					0.872 (p=0.8323)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					5.615 (0.2298)			
Exogeneity (C) test in reduced model							2.491 (p=0.1145)	
note: *** p<0.01, ** p<0.05, * p<0.1								

Annex 6. OLS and IV regression results on per capita expenditures for pearl millet producers

	olsexpen		ols_reducedexpen		ivexpen		ivexogexpen	
	coef	se	coef	se	coef	se	coef	se
advarameltot1	0.136*	0.076	0.080	0.083	-1.765	1.621	0.130*	0.071
housiz08	-0.089***	0.007			-0.086***	0.010	-0.091***	0.007
adequiv08	-0.074	0.051			0.005	0.090	-0.070	0.047
depratio08	-0.039	0.025			-0.042	0.031	-0.039*	0.023
age0809	0.003	0.003			0.005	0.004	0.003	0.003
Total number of household's members educated in 2008	0.017**	0.009			0.027**	0.013	0.018**	0.008
lnvaltoteq08	0.032**	0.013	0.012	0.014	0.029*	0.016	0.033***	0.012
lnvalbetail08	-0.000	0.007	-0.008	0.008	0.012	0.013	0.001	0.007
lnvalbien08	0.004	0.009	0.013	0.009	-0.001	0.011	0.004	0.008
totown08	0.019***	0.006	0.014**	0.006	0.016**	0.007	0.019***	0.005
avefert08	0.016	0.113	0.038	0.124	0.080	0.153	0.005	0.106
goofert08	0.108	0.078	0.090	0.086	0.074	0.100	0.107	0.073
vgofert08	0.152*	0.080	0.138	0.087	0.261*	0.134	0.154**	0.075
inherita08	-0.214**	0.108	-0.220*	0.118	-0.228*	0.134	-0.209**	0.101
rent08	0.209	0.157	0.181	0.171	0.368	0.236	0.211	0.148
collat08	-0.127	0.479	0.092	0.525	-0.004	0.601	-0.112	0.451
purcha08	0.150*	0.080	0.038	0.087	0.121	0.104	0.159**	0.075
sandy	-0.230***	0.078	-0.207**	0.085	-0.170	0.110	-0.232***	0.073
clay	-0.129	0.083	-0.158*	0.091	-0.150	0.105	-0.125	0.078
sandclay	0.007	0.074	-0.016	0.081	0.101	0.124	0.003	0.070
loamy	0.103	0.080	0.077	0.087	0.272	0.176	0.101	0.075
fagrpromar	0.042	0.067	0.075	0.074				
fcerdit	-0.032	0.102	-0.054	0.112				
fagrproduc	-0.021	0.037	-0.053	0.041				
mothergroup	-0.049	0.039	-0.076*	0.042				
lnreven08					-0.003	0.008	-0.004	0.006
_cons	9.901***	0.347	9.168***	0.347	10.291***	0.550	9.891***	0.327
Number of observations	958		958		958		958	
Adjusted R2	0.514		0.413		0.158		0.515	
F test od significance of variables dropped from restricted OLS and IV models	3.74 (p=0.5876)							
Hansen's J test of over-identifying restrictions					0.796 (p=0.9390)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					10.145 (p=0.0712)			
Exogeneity (C) test in reduced model					1.024 (0.3116)			
note: *** p<0.01, ** p<0.05, * p<0.1								

Annex 7 . OLS and IV regression results on average household average sorghum yield

	olsyield		ols_reducedyield		ivyld		Ivexogyld	
	coef	se	coef	se	coef	se	coef	se
advarameltot1	-18.967	38.390	-15.895	38.323	609.178	591.877	-15.895	36.183
housiz08	2.473	3.288						
adequiv08	16.699	22.492						
depratio08	-1.205	10.713						
age0809	-0.292	1.256						
Total number of household's members educated in 2008	6.506	3.978						
lnvaltoteq08	3.901	5.637	4.719	5.601	1.738	6.673	4.719	5.288
lnvalbetail08	-0.771	3.228	-0.056	3.183	2.108	3.999	-0.056	3.005
lnvalbien08	0.778	3.655	0.153	3.635	-0.105	3.934	0.153	3.432
totown08	-3.220	2.148	-2.393	2.100	-1.988	2.301	-2.393	1.983
avefert08	-36.329	49.487	-35.015	49.256	-68.700	61.988	-35.015	46.505
goofert08	9.488	33.461	11.178	33.263	15.759	36.186	11.178	31.406
vgofert08	23.886	33.754	22.661	33.668	-0.552	42.462	22.661	31.787
inherita08	3.360	46.030	8.397	45.938	-5.700	51.371	8.397	43.372
rent08	13.225	63.465	13.590	63.361	-0.641	69.741	13.590	59.822
collat08	174.956	207.475	146.803	206.999	41.345	244.759	146.803	195.437
purcha08	31.361	33.835	36.820	33.635	52.301	39.160	36.820	31.756
sandy	-67.307**	33.927	-70.394**	33.846	-49.198	41.679	-70.394**	31.956
clay	-54.308	35.518	-51.661	35.470	-66.421	40.768	-51.661	33.489
sandclay	85.387***	32.367	85.642***	32.334	67.296*	38.986	85.642***	30.528
loamy	70.825**	35.382	72.132**	35.350	88.049**	41.034	72.132**	33.376
fagrpromar	56.396	37.355	52.046	37.218	59.040	40.736	52.046	35.139
fcerdit	-37.526	35.819	-39.277	35.818	-25.706	40.754	-39.277	33.817
fagrproduc	3.149	18.372	5.888	18.227	14.267	21.217	5.888	17.209
mothergroup	-9.246	19.413	-8.898	19.394	-24.528	25.627	-8.898	18.311
nrainfall==2	-164.563	199.415	-170.170	198.885	-740.822***	195.941	-721.825***	170.565
nrainfall==3	-208.311	250.572	-230.931	247.582	-40.352	322.351	-230.931	233.754
nrainfall==4	-164.697	228.187	-153.229	225.180	-152.004	243.211	-153.229	212.604
nrainfall==5	-432.591***	161.105	-424.099***	159.065	-429.812**	171.884	-424.099***	150.181
nrainfall==6	-413.195**	188.500	-397.151**	186.452	-348.435*	206.570	-397.151**	176.038
_cons	1,067.17***	165.18	1,121.86***	144.62	1,173.94***	163.76	1,121.86***	136.542
Number of observations	967		967		967		967	
Adjusted R2	0.309		0.308		0.094		0.308	
F test od significance of variables dropped from restricted OLS and IV models	1.24 (p=0.2871)							
Hansen's J test of over-identifying restrictions					4.198 (0.3799)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					4.729 (0.4498)			
Exogeneity (C) test in reduced model							1.467 (0.2259)	
note: *** p<0.01, ** p<0.05, * p<0.1								

Annex 8 . OLS and IV regression results on per capita total value of production of sorghum producers.

	olstvp		ols_reducedtvp		ivtvp		ivexogtvp	
	Coef	se	coef	Se	Coef	se	coef	se
advarameltot1	0.366**	0.183	0.358**	0.183	-2.931	4.024	0.358**	0.173
housiz08	0.013	0.016						
adequiv08	-0.415***	0.108	-0.401***	0.107	-0.450***	0.132	-0.401***	0.101
depratio08	-0.014	0.051						
age0809	0.002	0.006						
Total number of household's members educated in 2008	0.044**	0.019	0.052***	0.017	0.062***	0.022	0.052***	0.016
lnvaltoteq08	0.040	0.027	0.042	0.027	0.067	0.043	0.042*	0.026
lnvalbetail08	0.051***	0.015	0.054***	0.015	0.045**	0.020	0.054***	0.014
lnvalbien08	0.055***	0.018	0.055***	0.018	0.054***	0.019	0.055***	0.017
totown08	0.007	0.010	0.009	0.010	0.005	0.012	0.009	0.010
avefert08	-0.246	0.243	-0.247	0.242	-0.120	0.308	-0.247	0.230
goofert08	0.169	0.162	0.183	0.161	0.118	0.194	0.183	0.153
vgofert08	0.291*	0.163	0.298*	0.163	0.324*	0.181	0.298*	0.154
inherita08	0.339	0.220	0.324	0.219	0.425	0.270	0.324	0.207
rent08	-0.239	0.312	-0.272	0.310	-0.235	0.344	-0.272	0.294
collat08	0.838	1.037	0.812	1.035	1.403	1.347	0.812	0.980
purcha08	0.289*	0.163	0.303*	0.162	0.249	0.190	0.303**	0.154
sandy	-0.192	0.164	-0.206	0.163	-0.271	0.196	-0.206	0.155
clay	-0.043	0.171	-0.057	0.171	0.086	0.256	-0.057	0.162
sandclay	0.197	0.155	0.198	0.155	0.296	0.208	0.198	0.147
loamy	0.332**	0.167	0.337**	0.167	0.241	0.217	0.337**	0.158
fagrpromar	-0.339*	0.186	-0.352*	0.185	-0.370*	0.204	-0.352**	0.175
fcerdit	0.107	0.179	0.092	0.179	0.032	0.210	0.092	0.169
fagrproduc	-0.179**	0.091	-0.190**	0.090	-0.221**	0.106	-0.190**	0.086
mothergroup	-0.139	0.095						
cons	8.966***	0.740	9.059***	0.689	8.793***	0.824	9.059***	0.653
Number of observations	1,047		1,047		1,047		1,047	
Adjusted R2	0.377		0.378		0.163		0.378	
F test od significance of variables dropped from restricted OLS and IV models	0.75 (p=0.5555)							
Hansen's J test of over-identifying restrictions					1.832 (p=0.608)			
Anderson canonical correlation LR statistic in IV model (test for IV model underidentification)					2.603 (p=0.6263)			
Exogeneity (C) test in reduced model							0.901 (p=0.3424)	
note: *** p<0.01, ** p<0.05, * p<0.1								

Annex 9 . OLS and IV regression results on per capita total revenues of sorghum producers.

	olsrev		ols_reducedrev		ivrev		ivexogrev	
	coef	**se**	**coef**	**se**	**Coef**	**se**	**coef**	**se**
advarameltot1	0.338**	0.144	0.341**	0.144	1.630	2.665	0.341**	0.136
housiz08	0.007	0.012						
adequiv08	-0.557***	0.085	-0.535***	0.084	-0.517***	0.091	-0.535***	0.080
depratio08	0.014	0.040						
age0809	0.006	0.005						
Total number of household's members educated in 2008	0.020	0.015						
lnvaltoteq08	0.081***	0.021	0.084***	0.021	0.074**	0.030	0.084***	0.020
lnvalbetail08	0.206***	0.012	0.209***	0.012	0.212***	0.013	0.209***	0.011
lnvalbien08	0.028**	0.014	0.026*	0.014	0.026*	0.014	0.026**	0.013
totown08	0.001	0.008	0.005	0.008	0.006	0.008	0.005	0.008
avefert08	0.134	0.191	0.124	0.191	0.075	0.214	0.124	0.181
goofert08	0.114	0.127	0.113	0.127	0.138	0.136	0.113	0.120
vgofert08	0.205	0.128	0.195	0.128	0.185	0.128	0.195	0.121
inherita08	0.270	0.172	0.264	0.172	0.225	0.188	0.264	0.163
rent08	-0.048	0.245	-0.077	0.245	-0.085	0.242	-0.077	0.232
collat08	0.554	0.815	0.492	0.814	0.267	0.928	0.492	0.771
purcha08	0.297**	0.128	0.320**	0.127	0.340**	0.132	0.320***	0.121
sandy	-0.052	0.129	-0.060	0.129	-0.034	0.138	-0.060	0.122
clay	-0.167	0.135	-0.166	0.135	-0.220	0.173	-0.166	0.128
sandclay	0.184	0.122	0.188	0.122	0.148	0.145	0.188	0.115
loamy	0.334**	0.131	0.344***	0.131	0.380**	0.149	0.344***	0.124
fagrpromar	-0.639***	0.146	-0.638***	0.146	-0.627***	0.146	-0.638***	0.138
fcerdit	0.215	0.141	0.211	0.141	0.237	0.149	0.211	0.133
fagrproduc	-0.005	0.072	0.008	0.071	0.021	0.075	0.008	0.068
mothergroup	-0.120	0.075	-0.124*	0.075	-0.143*	0.084	-0.124*	0.071
_cons	8.731***	0.581	9.159***	0.541	9.256***	0.571	9.159***	0.512
Number of observations	1,047		1,047		1,047		1,047	
Adjusted R2	0.489		0.488		0.444		0.488	
F test od significance of variables dropped from restricted OLS and IV models	1.71 (p=0.1456)							
Hansen's J test of over-identifying restrictions					6.769 (p=0.0796)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					2.965 (p=00.5638)			
Exogeneity (C) test in reduced model							0.255 (p=0.6139)	
note: *** p<0.01, ** p<0.05, * p<0.1								

Annex 10. OLS and IV regression results on per capita total wealth of sorghum producers

	olswealth		ols_reducedwealth		ivwealth		ivexogwealth	
	Coef	se	coef	Se	coef	se	coef	se
advarameltot1	0.037	0.098	0.036	0.098	-0.853	2.384	0.036	0.093
housiz08	0.034***	0.008	0.034***	0.008	0.035***	0.009	0.034***	0.008
adequiv08	-0.426***	0.058	-0.425***	0.057	-0.436***	0.065	-0.425***	0.054
depratio08	-0.009	0.027	-0.009	0.027	-0.015	0.033	-0.009	0.026
age0809	0.002	0.003	0.002	0.003	0.001	0.004	0.002	0.003
Total number of household's members educated in 2008	0.008	0.010	0.008	0.010	0.011	0.013	0.008	0.010
totown08	0.025***	0.006	0.025***	0.005	0.025***	0.006	0.025***	0.005
avefert08	-0.095	0.131	-0.091	0.129	-0.062	0.151	-0.091	0.123
goofert08	-0.141	0.087	-0.144*	0.086	-0.164	0.101	-0.144*	0.081
vgofert08	0.128	0.088	0.130	0.087	0.136	0.088	0.130	0.083
inherita08	0.199*	0.118	0.192	0.118	0.216	0.133	0.192*	0.112
rent08	-0.124	0.168	-0.133	0.167	-0.128	0.166	-0.133	0.158
collat08	0.176	0.558	0.172	0.557	0.347	0.725	0.172	0.529
purcha08	0.293***	0.087	0.292***	0.087	0.281***	0.091	0.292***	0.082
sandy	0.022	0.088	0.018	0.088	0.002	0.098	0.018	0.083
clay	-0.133	0.092	-0.138	0.091	-0.098	0.140	-0.138	0.087
sandclay	0.007	0.083	0.009	0.083	0.036	0.110	0.009	0.079
loamy	0.059	0.090	0.059	0.089	0.035	0.110	0.059	0.085
fagrpromar	0.001	0.100						
fcerdit	-0.075	0.096						
fagrproduc	0.021	0.049						
mothergroup	-0.044	0.051						
_cons	13.125***	0.355	13.125***	0.354	13.146***	0.355	13.125***	0.336
Number of observations	1,047		1,047		1,047		1,047	
Adjusted R2	0.287		0.289		0.227		0.289	
F test od significance of variables dropped from restricted OLS and IV models	0.39 (p=0.8162)							
Hansen's J test of over-identifying restrictions					1.458 (p=0.6919)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					1.736 (0.784)			
Exogeneity (C) test in reduced model							0.151 (p=0.6974)	
note: *** p<0.01, ** p<0.05, * p<0.1								

Annex 11. OLS and IV regression results on per capita cereal availability of sorghum producers

	olscapi1		ols_reducedcapi1		ivcapi1		ivexogcapi1	
	Coef	se	coef	se	coef	se	coef	se
advarameltot1	-16.468	36.115	-17.611	36.054	-705.658	987.376	-17.611	34.126
housiz08	-32.372***	3.143	-32.645***	3.131	-32.000***	3.612	-32.645***	2.963
adequiv08	-43.536**	21.311	-41.738**	21.191	-48.896*	25.765	-41.738**	20.057
depratio08	1.433	10.096	1.032	10.072	-4.303	13.590	1.032	9.533
age0809	0.784	1.198	0.894	1.193	0.097	1.754	0.894	1.129
Total number of household's members educated in 2008	5.644	3.793	5.686	3.786	7.948	5.323	5.686	3.583
lnvaltoteq08	16.340***	5.378	16.421***	5.371	21.573**	9.510	16.421***	5.084
lnvalbetail08	7.836***	2.992	8.121***	2.970	6.284	4.231	8.121***	2.811
lnvalbien08	0.103	3.495	0.431	3.480	0.198	3.896	0.431	3.294
lnreven08	-4.014	2.769	-3.931	2.765	-2.663	3.580	-3.931	2.617
totown08	7.024***	2.048	7.084***	2.046	6.462***	2.450	7.084***	1.936
avefert08	-15.696	47.895	-18.412	47.467	5.962	63.432	-18.412	44.928
goofert08	-14.492	31.910	-14.760	31.474	-31.677	42.667	-14.760	29.791
vgofert08	51.027	32.195	52.555	32.066	56.493	36.204	52.555*	30.351
inherita08	56.529	43.591	54.750	43.483	71.044	53.828	54.750	41.157
rent08	142.994**	61.668	137.013**	61.381	141.744**	68.789	137.013**	58.098
collat08	-84.644	204.735	-79.626	204.412	50.914	294.962	-79.626	193.480
purcha08	45.876	32.302	46.716	32.203	34.795	39.774	46.716	30.480
sandy	-65.312**	32.356	-65.940**	32.306	-79.655*	41.047	-65.940**	30.578
clay	-50.311	33.831	-51.977	33.622	-21.961	57.081	-51.977	31.824
sandclay	24.203	30.735	25.499	30.678	48.360	47.381	25.499	29.037
loamy	91.703***	32.946	91.711***	32.915	71.781	46.520	91.711***	31.155
fagrpromar	15.876	36.770						
fcerdit	1.807	35.330						
fagrproduc	-6.620	17.994						
mothergroup	-27.012	18.786						
_cons	259.207*	146.611	243.182*	146.062	216.986	167.167	243.182*	138.250
Number of observations	1,047		1,047		1,047		1,047	
Adjusted R2	0.350		0.351		0.099		0.351	
F test od significance of variables dropped from restricted OLS and IV models	0.60 (p=0.6617)							
Hansen's J test of over-identifying restrictions					1.451 (0.6936)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					1.736 (0.7841)			
Exogeneity (C) test in reduced model							0.675 (p=0.4112)	

note: *** p<0.01, ** p<0.05, * p<0.1

Annex 12. OLS and IV regression results on per capita expenditure of sorghum producers

	olsexpen		ols_reducedexpen		ivexpen		ivexogexpen	
	Coef	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
advarameltot1	0.141	0.089	0.148	0.097	1.781	1.939	0.150*	0.084
housiz08	-0.086***	0.008			-0.089***	0.009	-0.089***	0.007
adequiv08	-0.084	0.052			-0.057	0.061	-0.074	0.049
depratio08	-0.026	0.025			0.003	0.042	-0.023	0.024
age0809	0.004	0.003			0.006	0.004	0.004	0.003
Total number of household's members educated in 2008	0.016*	0.009			0.010	0.013	0.016*	0.009
lnvaltoteq08	0.021	0.013	0.005	0.014	0.012	0.018	0.021*	0.012
lnvalbetail08	0.003	0.007	-0.008	0.008	0.008	0.009	0.006	0.007
lnvalbien08	0.002	0.009	0.013	0.009	0.004	0.010	0.003	0.008
totown08	0.020***	0.006	0.016***	0.006	0.023***	0.007	0.020***	0.005
avefert08	0.111	0.115	0.152	0.124	0.045	0.136	0.088	0.108
goofert08	0.149*	0.079	0.121	0.085	0.202*	0.108	0.147**	0.073
vgofert08	0.227***	0.080	0.196**	0.086	0.253***	0.095	0.224***	0.075
inherita08	-0.117	0.108	-0.117	0.116	-0.131	0.122	-0.111	0.102
rent08	0.213	0.151	0.184	0.162	0.225	0.167	0.227	0.142
collat08	-0.152	0.483	0.074	0.521	-0.396	0.639	-0.103	0.455
purcha08	0.118	0.080	0.024	0.086	0.181*	0.100	0.143*	0.076
sandy	-0.172**	0.079	-0.127	0.085	-0.152*	0.090	-0.169**	0.075
clay	-0.140*	0.082	-0.208**	0.089	-0.243*	0.146	-0.147*	0.077
sandclay	0.077	0.075	0.069	0.082	-0.002	0.119	0.069	0.071
loamy	0.135*	0.080	0.122	0.087	0.155	0.095	0.127*	0.076
fagrpromar	-0.059	0.089	-0.020	0.095				
fcerdit	-0.026	0.106	-0.016	0.115				
fagrproduc	-0.057	0.044	-0.099**	0.047				
mothergroup	-0.083*	0.045	-0.107**	0.049				
lnreven08					-0.014*	0.008	-0.011*	0.006
_cons	9.682***	0.358	8.926***	0.349	9.679***	0.398	9.695***	0.337
Number of observations	962		962		962		962	
Adjusted R2	0.501		0.415		0.305		0.500	
F test od significance of variables dropped from restricted OLS and IV models	1.71 (p=0.1452)							
Hansen's J test of over-identifying restrictions					4.803 (0.1868)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					2.521 (0.6409)			
Exogeneity (C) test in reduced model							0.987 (0.3205)	
note: *** p<0.01, ** p<0.05, * p<0.1								

Annex 13. OLS and IV regression results on per capita sorghum sale by sorghum producers

	olsvente		ols_reducedvente		ivvente		ivexogvente	
	coef	se	coef	se	coef	se	coef	se
advarameltot1	0.544**	0.270	0.516*	0.268	-2.264	2.705	0.516**	0.254
housiz08	0.012	0.026						
adequiv08	-0.119	0.183						
depratio08	0.095	0.087						
age0809	-0.011	0.011						
Total number of household's members educated in 2008	-0.024	0.031						
lnvaltoteq08	0.076*	0.046	0.077*	0.045	0.080*	0.045	0.077*	0.043
lnvalbetail08	0.003	0.026	-0.002	0.026	0.011	0.029	-0.002	0.024
totown08	0.049***	0.018	0.049***	0.018	0.047***	0.018	0.049***	0.017
cellular081	0.118	0.246	0.172	0.243	0.167	0.243	0.172	0.230
radio081	0.108	0.281	0.118	0.280	0.332	0.348	0.118	0.265
television081	-0.737*	0.396	-0.661*	0.390	-0.452	0.439	-0.661*	0.370
avefert08	0.129	0.408	0.092	0.406	0.190	0.417	0.092	0.385
goofert08	-0.317	0.277	-0.325	0.276	-0.338	0.276	-0.325	0.261
vgofert08	0.653**	0.279	0.696**	0.278	0.848***	0.315	0.696***	0.263
inherita08	-0.338	0.381	-0.349	0.380	-0.322	0.381	-0.349	0.360
rent08	0.181	0.560	0.213	0.557	0.478	0.613	0.213	0.528
collat08	-0.390	1.779	-0.237	1.773	-0.005	1.786	-0.237	1.678
purcha08	0.360	0.282	0.339	0.279	0.366	0.280	0.339	0.264
sandy	-0.368	0.278	-0.355	0.277	-0.336	0.278	-0.355	0.263
clay	-0.550*	0.300	-0.544*	0.299	-0.600**	0.304	-0.544*	0.283
sandclay	-0.071	0.264	-0.065	0.263	-0.026	0.266	-0.065	0.249
loamy	0.023	0.285	-0.013	0.284	0.197	0.349	-0.013	0.269
fagrpromar	0.170	0.245	0.140	0.243	0.062	0.255	0.140	0.231
fcerdit	0.012	0.298	0.007	0.298	-0.005	0.298	0.007	0.282
fagrproduc	0.079	0.135	0.091	0.135	0.127	0.139	0.091	0.127
mothergroup	-0.277**	0.141	-0.257*	0.140	-0.179	0.159	-0.257*	0.133
_cons	0.123	1.226	-0.419	1.086	0.310	1.295	-0.419	1.028
Number of observations	1,044		1,044		1,044		1,044	
Adjusted R2	0.481		0.481		0.422		0.481	
F test od significance of variables dropped from restricted OLS and IV models	1.36 (p=0.2358)							
Hansen's J test of over-identifying restrictions					7.272 (p=0.1222)			
Anderson canonical correlation LR statistic in IV model (test for IV model undridentification)					3.353 (p=0.6458)			
Exogeneity (C) test in reduced model							0.102 (p=0.75)	

note: *** p<0.01, ** p<0.05, * p<0.1

Annex 14. Results of balancing tests for propensity score matching – adopters and non-adopters based on modern pearl millet varieties on pearl millet yield

		Mean		% reduction		t-test	
Variable	Sample	Treated	Control	%bias	bias	t	P > t
housiz08	Unmatched	10.149	9.985	3		0.47	0.64
	Matched	10.17	9.8421	6	-100.5	0.8	0.427
adequiv08	Unmatched	2.2612	2.2319	4.3		0.67	0.503
	Matched	2.2628	2.2203	6.3	-44.8	0.86	0.389
depratio08	Unmatched	1.3244	1.3446	-1.5		-0.23	0.815
	Matched	1.3148	1.2514	4.6	-213.8	0.63	0.53
age0809	Unmatched	51.335	50.359	8.5		1.32	0.186
	Matched	51.381	53.553	-18.9	-122.6	-2.4	0.017
eductthh_08	Unmatched	4.1526	4.1182	0.8		0.12	0.902
	Matched	4.1878	4.1547	0.8	3.7	0.1	0.924
avefert08	Unmatched	0.08447	0.09158	-2.5		-0.38	0.7
	Matched	0.08011	0.08287	-1	61.2	-0.14	0.892
goofert08	Unmatched	0.48501	0.54653	-12.3		-1.9	0.057
	Matched	0.48066	0.51657	-7.2	41.6	-0.97	0.335
vgofert08	Unmatched	0.61308	0.51108	20.6		3.17	0.002
	Matched	0.61602	0.5884	5.6	72.9	0.76	0.448
inherita08	Unmatched	0.89646	0.85524	12.5		1.89	0.059
	Matched	0.89503	0.91989	-7.5	39.7	-1.15	0.249
rent08	Unmatched	0.06267	0.02954	15.8		2.58	0.01
	Matched	0.06077	0.01934	19.8	-25.1	2.86	0.004
collat08	Unmatched	0.00272	0.00443	-2.9		-0.43	0.67
	Matched	0.00276	0.00276	0	100	0	1
purcha08	Unmatched	0.29155	0.33826	-10.1		-1.54	0.123
	Matched	0.29558	0.25138	9.5	5.4	1.33	0.183
sandy	Unmatched	0.30518	0.43722	-27.6		-4.21	0
	Matched	0.30387	0.24862	11.5	58.2	1.66	0.097
clay	Unmatched	0.23978	0.19645	10.5		1.64	0.102
	Matched	0.24033	0.26243	-5.4	49	-0.68	0.494
sandclay	Unmatched	0.40054	0.38848	2.5		0.38	0.703
	Matched	0.39503	0.35359	8.5	-243.4	1.15	0.25
loamy	Unmatched	0.52589	0.35303	35.3		5.49	0
	Matched	0.52486	0.52762	-0.6	98.4	-0.07	0.941
fagrpromar	Unmatched	0.03815	0.04579	-1.7		-0.25	0.806
	Matched	0.03591	0.03867	-0.6	63.9	-0.09	0.93
fcerdit	Unmatched	0.0436	0.06499	-5.3		-0.83	0.406
	Matched	0.0442	0.01105	8.2	-54.9	1.4	0.162
fagrproduc	Unmatched	0.28338	0.11817	17.5		3	0.003
	Matched	0.1989	0.17956	2.1	88.3	0.31	0.759
mothergroup	Unmatched	0.21526	0.12555	10.5		1.65	0.099
	Matched	0.21823	0.16022	6.8	35.3	0.96	0.335
jigawa	Unmatched	0.12807	0.19055	-17.1		-2.58	0.01
	Matched	0.12983	0.13536	-1.5	91.2	-0.22	0.827
kano	Unmatched	0.29155	0.21418	17.9		2.8	0.005
	Matched	0.29558	0.26519	7	60.7	0.91	0.363
katsina	Unmatched	0.18801	0.19793	-2.5		-0.39	0.699
	Matched	0.19061	0.22652	-9.1	-262	-1.19	0.235
yobe	Unmatched	0.0327	0.15214	-42.1		-5.98	0
	Matched	0.03315	0.02762	1.9	95.4	0.43	0.666
zamfara	Unmatched	0.22888	0.14771	20.9		3.3	0.001
	Matched	0.22376	0.23204	-2.1	89.8	-0.27	0.791

Annex 15. Results of balancing tests for propensity score matching – adopters and non-adopters based per capita expenditures

Variable	Sample	Treated	Control	%bias	bias	t	p>t
housiz08	Unmatched	9.9685	9.9469	0.4		0.06	0.952
	Matched	9.9772	9.6915	5.3	-1225.3	0.71	0.477
adequiv08	Unmatched	2.2339	2.2232	1.6		0.23	0.816
	Matched	2.2352	2.1983	5.5	-245.8	0.72	0.474
depratio08	Unmatched	1.2907	1.3464	-4.1		-0.63	0.531
	Matched	1.2776	1.2584	1.4	65.4	0.2	0.844
age0809	Unmatched	51.059	50.294	6.6		0.99	0.324
	Matched	51.118	51.817	-6.1	8.6	-0.76	0.447
eductthh_08	Unmatched	4.1562	4.1952	-0.9		-0.13	0.894
	Matched	4.1854	3.8085	8.9	-865.3	1.18	0.237
avefert08	Unmatched	0.09009	0.0928	-0.9		-0.14	0.89
	Matched	0.08511	0.07295	4.2	-348.7	0.58	0.564
goofert08	Unmatched	0.48649	0.552	-13.1		-1.94	0.053
	Matched	0.48024	0.54711	-13.4	-2.1	-1.72	0.086
vgofert08	Unmatched	0.62162	0.4992	24.8		3.64	0
	Matched	0.62614	0.59878	5.5	77.7	0.72	0.472
inherita08	Unmatched	0.9009	0.856	13.8		1.98	0.048
	Matched	0.8997	0.88754	3.7	72.9	0.51	0.614
rent08	Unmatched	0.06306	0.0304	15.5		2.41	0.016
	Matched	0.06383	0.02736	17.3	-11.7	2.25	0.025
collat08	Unmatched	0.003	0.0048	-2.9		-0.41	0.682
	Matched	0.00304	0.00304	0	100	0	1
purcha08	Unmatched	0.28228	0.3376	-12		-1.75	0.08
	Matched	0.28571	0.2614	5.3	56	0.7	0.485
sandy	Unmatched	0.3033	0.4432	-29.2		-4.25	0
	Matched	0.30091	0.2614	8.2	71.8	1.13	0.26
clay	Unmatched	0.25225	0.2	12.5		1.87	0.062
	Matched	0.25532	0.26444	-2.2	82.5	-0.27	0.79
sandclay	Unmatched	0.41441	0.3776	7.5		1.11	0.266
	Matched	0.41033	0.48632	-15.5	-106.4	-1.96	0.05
loamy	Unmatched	0.53153	0.3488	37.4		5.55	0
	Matched	0.53191	0.5228	1.9	95	0.23	0.815
fagrpromar	Unmatched	0.03303	0.0496	-3.7		-0.49	0.623
	Matched	0.03343	0.01216	4.7	-28.4	1.41	0.159
fcerdit	Unmatched	0.02102	0.0704	-15.7		-2.13	0.034
	Matched	0.02128	0.01216	2.9	81.5	0.66	0.512
fagrproduc	Unmatched	0.3003	0.12	18.5		3.04	0.002
	Matched	0.20669	0.23404	-2.8	84.8	-0.39	0.696
mothergroup	Unmatched	0.22823	0.1344	10.6		1.59	0.112
	Matched	0.231	0.41337	-20.6	-94.4	-1.95	0.052
jigawa	Unmatched	0.13514	0.2032	-18.2		-2.62	0.009
	Matched	0.13678	0.16109	-6.5	64.3	-0.88	0.382
kano	Unmatched	0.2973	0.2016	22.2		3.34	0.001
	Matched	0.30091	0.21884	19.1	14.2	2.41	0.016
katsina	Unmatched	0.18318	0.2	-4.3		-0.63	0.531
	Matched	0.18541	0.19149	-1.5	63.9	-0.2	0.842
yobe	Unmatched	0.03303	0.16	-44		-5.95	0
	Matched	0.03343	0.03343	0	100	0	1
zamfara	Unmatched	0.23724	0.1488	22.5		3.41	0.001
	Matched	0.23404	0.26444	-7.7	65.6	-0.9	0.368

Annex 16. Results of balancing tests for propensity score matching – adopters and non-adopters based on modern sorghum varieties on yield.

Variable	Sample	Treated	Control	%bias	bias	t	p>t
housiz08	Unmatched	9.5594	9.9291	-7		-0.97	0.332
	Matched	9.5594	9.214	6.5	6.6	0.79	0.428
adequiv08	Unmatched	2.2252	2.2244	0.1		0.02	0.986
	Matched	2.2252	2.2237	0.2	-76.3	0.02	0.981
depratio08	Unmatched	1.1451	1.3778	-18		-2.47	0.014
	Matched	1.1451	1.2128	-5.2	70.9	-0.62	0.535
age0809	Unmatched	51.587	50.119	12.6		1.79	0.074
	Matched	51.587	50.659	8	36.8	0.9	0.37
eductthh_08	Unmatched	4.2023	3.8684	8		1.14	0.253
	Matched	4.2023	3.9844	5.2	34.8	0.58	0.565
agriculure08	Unmatched	0.91051	0.88228	9.3		1.25	0.211
	Matched	0.91051	0.91051	0	100	0	1
lnvaltoteq08	Unmatched	11.558	11.398	6.1		0.83	0.405
	Matched	11.558	11.643	-3.2	47.1	-0.4	0.692
lnvalbeta~08	Unmatched	9.3269	9.5913	-5.2		-0.73	0.467
	Matched	9.3269	9.4429	-2.3	56.1	-0.25	0.801
lnvalbien08	Unmatched	11.138	10.8	9.1		1.24	0.215
	Matched	11.138	11.287	-4	55.7	-0.51	0.613
lnreven08	Unmatched	5.5694	4.7231	15.4		2.15	0.032
	Matched	5.5694	5.8323	-4.8	68.9	-0.53	0.593
totown08	Unmatched	5.958	6.2617	-4.7		-0.6	0.549
	Matched	5.958	6.2539	-4.6	2.6	-0.56	0.578
avefert08	Unmatched	0.05837	0.0962	-14.2		-1.87	0.062
	Matched	0.05837	0.0428	5.8	58.9	0.8	0.422
goofert08	Unmatched	0.47471	0.53038	-11.1		-1.55	0.121
	Matched	0.47471	0.48638	-2.3	79	-0.26	0.792
vgofert08	Unmatched	0.55642	0.54937	1.4		0.2	0.844
	Matched	0.55642	0.57198	-3.1	-120.7	-0.36	0.723
inherita08	Unmatched	0.92996	0.82911	31.3		4	0
	Matched	0.92996	0.92607	1.2	96.1	0.17	0.865
rent08	Unmatched	0.04669	0.0443	1.1		0.16	0.873
	Matched	0.04669	0.05447	-3.7	-225.8	-0.4	0.688
collat08	Unmatched	0.00389	0.0038	0.2		0.02	0.983
	Matched	0.00389	0.00389	0	100	0	1
purcha08	Unmatched	0.23735	0.35949	-26.9		-3.64	0
	Matched	0.23735	0.22957	1.7	93.6	0.21	0.835
sandy	Unmatched	0.22957	0.41772	-41		-5.49	0
	Matched	0.22957	0.2179	2.5	93.8	0.32	0.751
clay	Unmatched	0.21401	0.23924	-6		-0.83	0.406
	Matched	0.21401	0.23735	-5.6	7.5	-0.63	0.528
sandclay	Unmatched	0.33852	0.39494	-11.7		-1.62	0.106
	Matched	0.33852	0.3463	-1.6	86.2	-0.19	0.853
loamy	Unmatched	0.5214	0.36962	30.9		4.34	0
	Matched	0.5214	0.50973	2.4	92.3	0.26	0.792
fagrpromar	Unmatched	0.01167	0.02911	-6		-0.7	0.487
	Matched	0.01167	0.02335	-4	33.1	-0.84	0.404
fcerdit	Unmatched	0.03113	0.05823	-6.7		-0.99	0.324
	Matched	0.03113	0.03113	0	100	0	1
fagrproduc	Unmatched	0.14397	0.15823	-2		-0.26	0.792
	Matched	0.14397	0.12062	3.3	-63.7	0.46	0.647
mothergroup	Unmatched	0.20623	0.10886	13.2		1.83	0.067
	Matched	0.20623	0.15175	7.4	44.1	0.86	0.391
jigawa	Unmatched	0.07782	0.18354	-31.7		-4.07	0
	Matched	0.07782	0.0856	-2.3	92.6	-0.32	0.748
kano	Unmatched	0.28016	0.22658	12.3		1.75	0.081
	Matched	0.28016	0.24514	8.1	34.6	0.9	0.368
katsina	Unmatched	0.24903	0.18354	15.9		2.28	0.023
	Matched	0.24903	0.27237	-5.7	64.3	-0.6	0.548
yobe	Unmatched	0.05837	0.12785	-24.1		-3.09	0.002
	Matched	0.05837	0.04669	4	83.2	0.59	0.554

Variable	Sample	Treated	Control	%bias	bias	t	p>t
zamfara	Unmatched	0.17899	0.15443	6.6		0.93	0.352
	Matched	0.17899	0.21012	-8.3	-26.8	-0.89	0.374

Annex 17. Results of balancing tests for propensity score matching – adopters and non-adopters based on par capita expenditure.

Variable	Sample	Treated	Control	%bias	bias	t	p>t
housiz08	Unmatched	9.5594	9.9291	-7		-0.97	0.332
	Matched	9.5594	9.214	6.5	6.6	0.79	0.428
adequiv08	Unmatched	2.2252	2.2244	0.1		0.02	0.986
	Matched	2.2252	2.2237	0.2	-76.3	0.02	0.981
depratio08	Unmatched	1.1451	1.3778	-18		-2.47	0.014
	Matched	1.1451	1.2128	-5.2	70.9	-0.62	0.535
age0809	Unmatched	51.587	50.119	12.6		1.79	0.074
	Matched	51.587	50.659	8	36.8	0.9	0.37
eductthh_08	Unmatched	4.2023	3.8684	8		1.14	0.253
	Matched	4.2023	3.9844	5.2	34.8	0.58	0.565
agriculure08	Unmatched	0.91051	0.88228	9.3		1.25	0.211
	Matched	0.91051	0.91051	0	100	0	1
lnvaltoteq08	Unmatched	11.558	11.398	6.1		0.83	0.405
	Matched	11.558	11.643	-3.2	47.1	-0.4	0.692
lnvalbeta~08	Unmatched	9.3269	9.5913	-5.2		-0.73	0.467
	Matched	9.3269	9.4429	-2.3	56.1	-0.25	0.801
lnvalbien08	Unmatched	11.138	10.8	9.1		1.24	0.215
	Matched	11.138	11.287	-4	55.7	-0.51	0.613
lnreven08	Unmatched	5.5694	4.7231	15.4		2.15	0.032
	Matched	5.5694	5.8323	-4.8	68.9	-0.53	0.593
totown08	Unmatched	5.958	6.2617	-4.7		-0.6	0.549
	Matched	5.958	6.2539	-4.6	2.6	-0.56	0.578
avefert08	Unmatched	0.05837	0.0962	-14.2		-1.87	0.062
	Matched	0.05837	0.0428	5.8	58.9	0.8	0.422
goofert08	Unmatched	0.47471	0.53038	-11.1		-1.55	0.121
	Matched	0.47471	0.48638	-2.3	79	-0.26	0.792
vgofert08	Unmatched	0.55642	0.54937	1.4		0.2	0.844
	Matched	0.55642	0.57198	-3.1	-120.7	-0.36	0.723
inherita08	Unmatched	0.92996	0.82911	31.3		4	0
	Matched	0.92996	0.92607	1.2	96.1	0.17	0.865
rent08	Unmatched	0.04669	0.0443	1.1		0.16	0.873
	Matched	0.04669	0.05447	-3.7	-225.8	-0.4	0.688
collat08	Unmatched	0.00389	0.0038	0.2		0.02	0.983
	Matched	0.00389	0.00389	0	100	0	1
purcha08	Unmatched	0.23735	0.35949	-26.9		-3.64	0
	Matched	0.23735	0.22957	1.7	93.6	0.21	0.835
sandy	Unmatched	0.22957	0.41772	-41		-5.49	0
	Matched	0.22957	0.2179	2.5	93.8	0.32	0.751
clay	Unmatched	0.21401	0.23924	-6		-0.83	0.406
	Matched	0.21401	0.23735	-5.6	7.5	-0.63	0.528
sandclay	Unmatched	0.33852	0.39494	-11.7		-1.62	0.106
	Matched	0.33852	0.3463	-1.6	86.2	-0.19	0.853
loamy	Unmatched	0.5214	0.36962	30.9		4.34	0
	Matched	0.5214	0.50973	2.4	92.3	0.26	0.792
fagrpromar	Unmatched	0.01167	0.02911	-6		-0.7	0.487
	Matched	0.01167	0.02335	-4	33.1	-0.84	0.404
fcerdit	Unmatched	0.03113	0.05823	-6.7		-0.99	0.324
	Matched	0.03113	0.03113	0	100	0	1
fagrproduc	Unmatched	0.14397	0.15823	-2		-0.26	0.792
	Matched	0.14397	0.12062	3.3	-63.7	0.46	0.647
mothergroup	Unmatched	0.20623	0.10886	13.2		1.83	0.067
	Matched	0.20623	0.15175	7.4	44.1	0.86	0.391
jigawa	Unmatched	0.07782	0.18354	-31.7		-4.07	0
	Matched	0.07782	0.0856	-2.3	92.6	-0.32	0.748
kano	Unmatched	0.28016	0.22658	12.3		1.75	0.081
	Matched	0.28016	0.24514	8.1	34.6	0.9	0.368
katsina	Unmatched	0.24903	0.18354	15.9		2.28	0.023
	Matched	0.24903	0.27237	-5.7	64.3	-0.6	0.548
yobe	Unmatched	0.05837	0.12785	-24.1		-3.09	0.002
	Matched	0.05837	0.04669	4	83.2	0.59	0.554

zamfara	Unmatched	0.17899	0.15443	6.6		0.93	0.352
	Matched	0.17899	0.21012	-8.3	-26.8	-0.89	0.374