Africa Research in Sustainable Intensification for the Next Generation

Sustainable Intensification of Key Farming Systems in the Sudan and Guinea Savanna of West Africa

Technical Report, 1 October 2015 to 31 March 2016

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Through action research and development partnerships, Africa RISING will create opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The three regional projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads the program's monitoring, evaluation and impact assessment. http://africa-rising.net/

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Partners and their roles

Name	Abbreviation	Ghana	Mali	Role/responsibility
Afrique Verte, Mali	[1]AMASSA		+	On-farm and household nutrition studies with ICRISAT
Association Malienne d'Eveil et de Developpement Durable	[1]AMEDD		+	On-farm field trials and household nutrition studies with ICRISAT
Agricultural Development and Value Chain Enhancement Program	ADVANCE II	+		Assist with market linkages, joint demonstration of technologies
Animal Research Institute	ARI	+		R4D on livestock production (sheep and goats) with ILRI
Agricultural Technology Transfer Project	ATT	+		Assist with the introduction of new labor-saving technologies
The World Vegetable Center	AVRDC	+	+	Lead R4D on vegetable production systems
Community-based Organizations	CBOs	+	+	On-farm implementation of R4D activities
International Center for Tropical Agriculture	CIAT	+		Lead R4D on land and soil management
Compagnie Malienne de Developpement des Textiles	CMDT		+	On-farm field trials and household nutrition studies with ICRISAT
Crops Research Institute	CRI	+		Breeder seed of improved cereals and legumes
Food Research Institute	FRI	+		Household nutrition
Grains and Legumes Development Board	GLDB	+		Production of foundation seeds
Heifer International	[1]HI	+		On-farm livestock production with IITA
World Agroforestry Center	ICRAF		+	Lead R4D on agroforestry systems
International Crops Research Institute for the Semi-arid Tropics	ICRISAT	+	+	Sorghum/millet–groundnut R4D with IITA and SARI
International Food Policy Research Institute	IFPRI	+	+	Baseline survey and monitoring and evaluation
Institut d'Economie Rurale	IER		+	Socioeconomic and on-farm studies with ICRISAT
International Institute of Tropical Agriculture	IITA	+	+	Project coordination and R4D research on cereal–legumes.

International Livestock Research Institute	ILRI	+	+	Lead R4D on livestock, especially ruminants
Institute for Scientific and Technological Information	INSTI	+		Organize training and publish project document with IITA
International Water Management Institute	IWMI	+		Lead R4D on water management
Kwame Nkrumah University of Science and Technology	KNUST	+		Graduate student training and R4D on rural pig production
Mouvement Biologique du Mali	[1]MOBIOM		+	On-farm and household nutrition studies with ICRISAT
Ministry of Food and Agriculture	MoFA	+		Scaling-out SI technologies and establishment of R4D platforms
Ministry of Health	MoH	+		Household nutrition R4D with UDS and IITA
Presbyterian Agricultural Services	[1]PRA	+		SI technologies on soil fertility management with IITA
Savanna Agricultural Research Institute	SARI	+		R4D on cereal-legume-veg. systems with IITA, ICRISAT, and AVRDC
Seed Producers Association of Ghana	[1]SEEDPAG	+		Production of certified seeds and training on seed production
Soil Research Institute	SRI	+		R4D on integrated soil fertility management with IITA
University for Development Studies	UDS	+		Graduate training and R4D on rural poultry and pig production
Wageningen University, The Netherlands	WU	+	+	R4D on farming systems characterization and graduate training
Water Resources Institute, Ghana	WRI	+		R4D on water management with IWMI and CIAT

[1]Nongovernmental organization

Summary

Implemented work and achievements for the period October 2015 to March 2016 for the Africa RISING project in West Africa (Ghana and Mali) are reported.

For Mali, the report focuses on research results related to the established Research-for-Development Platforms such as their impact on technology adoption and network analysis. In addition, results from research on improved vegetable varieties and agronomic practices for intensified production, evaluation of indigenous fruit trees for leafy vegetable production, and agroforestry research to increase vegetable and fodder production are presented. Findings from the work on biophysical watershed characterization and analysis are also included, as well as from a survey on the nutritional status of women and children between 6 and 59 months of age.

Information presented from Ghana includes results from the economic analysis of sustainable intensification technologies; on-farm trials to identify and demonstrate crop (cereal, legume, vegetable) varieties and good agronomic practices (fertilizer application, cereal–legume rotations and intercropping, insect pest control) to intensify smallholder cereal–legume–vegetable systems; feeding and health management practices to intensify Guinea fowl production; and integrated maize–small ruminant production systems effects on grain production, soil chemical, physical and biological properties, and weed dynamics.

Increasing the capacity of young scientists continued to be a focus of the project. Twenty graduate students have been supervised or co-supervised by Africa RISING scientists during the reporting period.

In Ghana, the project has tried to intensify relations with other USAID-funded projects. Together with the country Mission a workshop was organized to present technologies tested by Africa RISING to USAID development projects for scaling out to their beneficiaries. A concrete outcome of these efforts is the application of the aflatoxin biocontrol product under development for Ghana in groundnut farmer field schools established by the SPRING project during the next season.

In Mali, the new Livestock Technology Scaling Project is scaling out the feed-health interventions package for improved small ruminant production developed by Africa RISING in Ghana.

The USAID commissioned External Program evaluation team completed their field work in Mali during October 2015.

Introduction

The project is being implemented in 25 intervention communities in the three northern regions of Ghana, and in nine villages in the Bougouni and Koutiala districts of the Sikasso Region in southern Mali.

Africa RISING is expected to result in spill over effects to other similar agroecological zones in the two countries and beyond. The 2014-2016 work plans presented fewer than five research themes. This report gives highlights of some activities implemented under those themes from October 2015 to March 2016.

Implemented work and achievements

1 Situation analysis (Output 1)

1.1 Socioeconomic assessment of the impact of research-for-development (R4D) platforms on adoption of sustainable intensification technologies in Mali

A survey involving 250 farm households in the intervention villages in southern Mali was conducted to test the hypothesis that R4D platforms can be used as a channel to increase adoption of sustainable intensification innovations. Six of the villages had been exposed to R4D platforms whilst four had not. In each village, members of 25 farm households (50% men and 50% women) were interviewed and GPS coordinates collected. The survey questionnaires addressed the following sections: household socioeconomic characteristics; use of agricultural technologies for sustainable intensification; access to agricultural input and output markets; access to credit and networks. Results are summarized under soil fertility management, crop management, livestock technologies, postharvest technologies, and farmers' perception of the role of the platforms on access to agricultural inputs.

1.1.1 Soil fertility management

The main practices used by farmers to restore soil fertility were chemical fertilizers, manure, and crop rotation. Adoption of the soil fertility improvement technologies did not differ between the platform-exposed and the non-exposed villages (Table 1).

Table 1: Proportion of respondents using soil fertility management practices

Main practices	Platform-exposed villages	Non-exposed villages
Chemical fertilizer	29	17
Manure	63	68
Crops rotation	5	8
Adoption rate of soil fertility management technologies (%)	45 P(t) = 0.5411	46

1.1.2 Crop management

Row planting and plant spacing, the main crop management practices used by farmers differed significantly among the platform exposed and non-exposed villages (Table 2). The difference could be partly due to closer interaction among farmers in the platform-exposed villages which facilitated information flows on crop management practices leading to significant adoption of the practices compared to the farmers in the non-platform exposed villages.

Table 2: Proportion of respondents using the following crop management practices

Main practices	Platform-exposed villages	Non-exposed villages
Row planting	69	63
Plant spacing	26	30
Adoption rate of crop management technologies (%)	40	30
	P(t) = 0.05	

1.1.3 Livestock technologies

Watering, fattening, and vaccination which were the key animal husbandry practices used by farmers did not differ significantly among farmers in the platform-exposed and non-exposed villages (Table 3). Similarly, use of a threshing machine (mechanization) which is the main postharvest technology used by farmers did not differ significantly among the two types of villages.

Table 3: Proportion of respondents using the following livestock management practices

Main practices	Platform-exposed villages	Non-exposed villages
Feeding	66	75
Watering	34	25
Adoption rate of crops management technologies (%)	98	100
	P(t) = 0.87	

1.1.4 Farmers' perception of the role of R4D platforms on access to agricultural inputs

Farmers identified five main constraints to accessing agricultural inputs (Table 4).

Table 4: Constraints to access agricultural inputs

Constraints	Before R4D Platform	With the R4D Platform	Difference
Not enough money	19.2	15.3	−3.9
Transport problem	3.7	4.4	+0.7
Far from home	8.4	6.7	−1.7
Lack of knowledge about use	1.2	0.8	−0.4
Inappropriate packaging	3.2	1.5	−1.7

1.2 Network analysis in Mali

A network analysis was also conducted to ascertain the level of interaction between farmers and actors in the R4D platform exposed and non-exposed villages. There were several noticeable differences in the network map of farmers between the two village categories.

In the non-platform exposed villages, the network is scattered with one larger and many smaller groups of farmers not connected to each other (Fig. 1). The majority of farmers only have one other farmer they share different resources with, which is quite different from the interconnected web between farmers in the R4D platform-exposed villages (Fig. 2). Farmers in the platform-exposed villages also seem to interact more intensely with each other which allows multiple information sharing between network members. This is indeed not surprising as one of the main objectives of the innovation platform is to improve the level of awareness and knowledge related to agricultural technologies among the rural communities through a better flow of information between farmers and other actors.

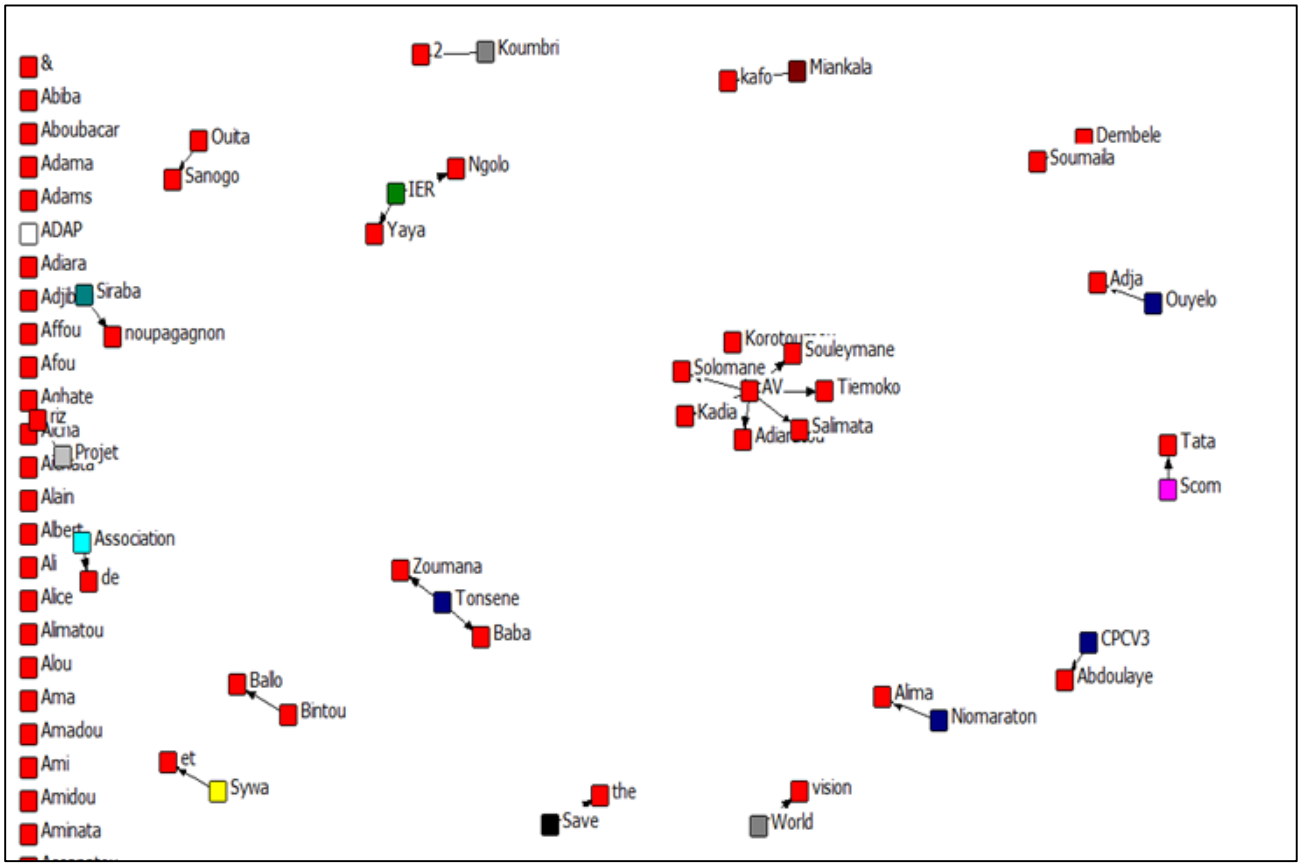

Figure 1: Network map of interactions among farmers in the non-platform exposed villages

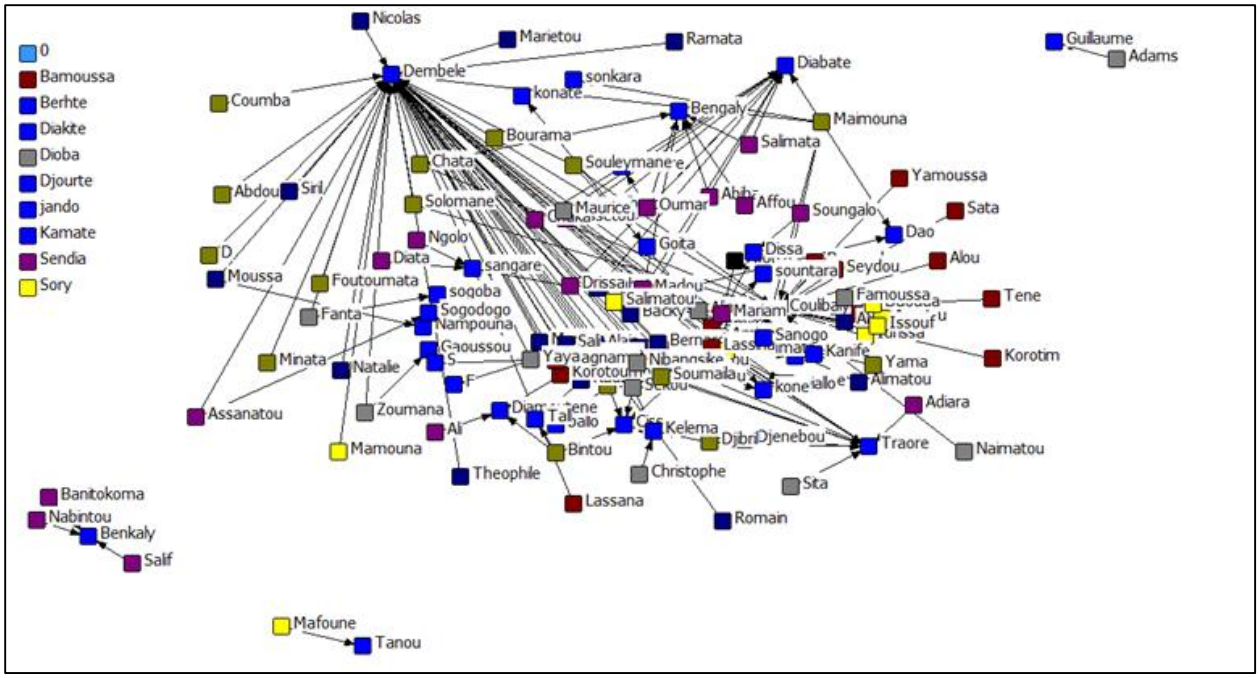

Figure 2: Network map of interactions among farmers in the R4D platform-exposed villages

1.3 Economic validation and monitoring adoption of sustainable intensification options in Ghana

Socioeconomic analysis of two trials was completed during the period. The first trial compared two insecticide application regimes (one application and three applications) as main plots and six cowpea varieties (Sangotra, Apagbaala, Padituya, IT 99K 573-1-1, Zaayura, and farmers' local variety) as sub-plots. Grain yields were measured and gross returns, return to labor per person day, benefit–cost ratio, and stochastic dominance were estimated.

Spraying cowpea three times had significant effects on financial net returns as compared to spraying only once. First degree stochastic dominance analysis also shows that the higher spray regime is dominant over the lower spray regime (Fig. 3). Spraying insecticides three times on cowpea not only increased grain yield and net returns, but also reduced the probability of getting lower yields and financial returns which makes it suitable to smallholder farmers who are usually risk averse.

The second trial evaluated the efficacy of a higher nitrogen application rate (90 kg/ha) against the government's sector Ministry recommended rate of 60 kg/ha. Tests were carried out to see whether the higher rate would generate better economic benefits and which fertilizer–variety combinations provide superior results. Six maize varieties, namely Abontem, TZEE W STR QPM CO, Abrohemaa, Omankwa, Obatampa, and DT SR W COFZ were used as sub-treatments. Yield data were collected from the agronomic trials. Average grain prices were collected from Tamale market which is the central market for the Northern Region of Ghana. Costs of labor, land, and draft power were estimated from Africa RISING baseline data while costs of commercial inputs (seeds, fertilizers, and pesticides) were collected from secondary data sources.

The higher rate of nitrogen application provides higher economic benefits to farmers compared to the government's sector Ministry's recommended rate (Table 5). There were differences among the six maize varieties in terms of performance under higher fertilizer application rates. The highest economic benefit was obtained when the higher rate of nitrogen was applied together with either variety TZEE W STR QPM CO or variety DT SRW COFZ (Table 6).

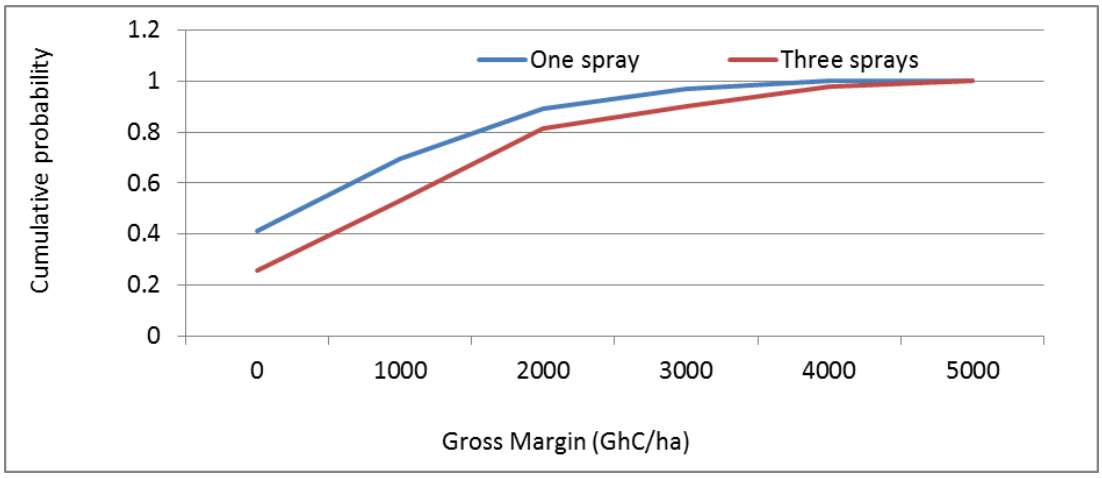

Figure 3: Stochastic dominance for spraying regime on cowpea (US$1 = GhC 3.3)

Table 5: Effect for nitrogen application on yield and economic outcomes

	Grain Yield (kg/ha)	Gross Margin (GhC/ha)	Benefit–Cost Ratio (BCR)	Returns to Labor (GhC/ha)
60 kg/ha N	3043(2251)	2791 (3152)	2.64 (1.95)	34 (35)
90 kg/ha N	3635(2318)	3460 (3246)	2.87 (1.83)	42 (36)
T-value	3.45***	2.78***	1.61	2.78***

***= significant at 1% level.

Table 6: Pairwise comparison of input options (technologies)

	Technology	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Rank**
1	60 kg/ha N + Abontem variety		S	S	S	S	S	S	H	H	H	H	H	11
2	60 kg/ha N + TZEE W STRQPM variety			S	S	S	S	S	H	S	S	S	H	7
3	6 0kg/ha N + Abrohama variety				S	S	S	S	H	H	H	H	H	11
4	60 kg/ha N + Omankwa variety					S	S	S	H	S	S	S	H	7
5	60 kg/ha N + Obatampa variety						S	S	H	S	S	S	H	7
6	60 kg/ha N + SR W COF2 variety							S	S	S	S	S	S	6
7	90 kg/ha N + Abontem variety								H	S	S	S	H	7
8	90 kg/ha N + TZEE W STRQPM variety									S	S	S	S	1
9	90 kg/ha N + Abrohama variety										S	S	S	3
10	90 kg/ha N + Omankwa variety											S	S	3
11	90 kg/ha N + Obatampa variety												S	3
12	90 kg/ha N + SR W COF2 variety													1

S = Technology in the 1st row is similar to the technology in the 2nd column corresponding to it.
H = Technology in the 1st row is higher than the technology in the 2nd column corresponding to it.

1.4 Farming systems analysis northern Ghana

Smallholder farming systems in northern Ghana exhibit low adoption rates of measures for sustainable intensification (SI) despite their proven effectiveness. Therefore, smallholder farm and farmer diversity in Northern Ghana was investigated with the aim to better understand technology adoption for SI. Statistical and participatory typologies were generated and combined to capture local smallholder diversity. Biophysical and socioeconomic information of each farm type was then collected to describe and explain the current system as well as to evaluate and explore alternatives for SI using the whole farm model Farm DESIGN. Whole farm modelling was performed at household level since the farm household forms a strong unit of agricultural production, with tight interdependencies in decision making, and exchanging and sharing resources like land, tools, labor, capital, inputs (fertilizers, seeds), and outputs (food, cash). However, different fields, crops, and livestock types are typically managed by different household members with different individual objectives and hence different interests and viewpoints on “improved farm technologies”. All household members who own fields were interviewed instead of the usual consultation of a single “representative” household member.

It was found that technologies for SI had different impacts and received different evaluations by the different household types and household members. The combination of whole-farm modelling and social contextualization revealed that technologies such as a systematic integration of maize and legumes seem technically simple and economically promising, but are difficult to implement if the crops are traditionally grown by different household members and on different fields. The need to distinguish between technologies and techniques was identified. While technologies are more technical (inputs, machinery) techniques are more managerial (behaviour change) making them differentially attractive and feasible for low- and high-resource endowed farm types. Analysing the social context of measures for SI gave a better understanding of challenges and opportunities for SI in smallholder systems in Northern Ghana.

2 Integrated systems improvement (Research Output 2)

2.1 Improving cereal–legume–vegetable cropping and integrated crop–livestock systems in Ghana

In Ghana, second year data collection for several experiments in the community-based Technology Parks in the three regions was completed and computerized. The computerized data for the Northern Region was cleaned and analyzed. Data cleaning and analysis for trials in the Upper East and Upper West regions are ongoing. Results of some selected experiments from the Northern Region are presented.

2.1.1 Nitrogen fertilizer rate for different maize maturity types in Northern Region

The effect of nitrogen fertilizer rates on improved varieties of maize were evaluated on farm using a split-plot design replicated in 10 communities. Main plots were two nitrogen fertilizer rates (government's sector Ministry recommended rate: 60-40-40 kg/ha and higher: 90-40-40 kg/ha NPK). Sub-plots were six improved maize varieties tolerant to drought and *Striga (*Extra Early: Abontem, TZEE W STR QPM C0; Early: Abrohema, Omankwa; Medium: Obatanpa and DT SR W C0 F2). Grain and stover yields were measured.

The main effects of year, nitrogen rate, and maize variety affected grain and stover yields (Table 7). A Nitrogen rate of 90 kg/ha may be used to improve grain yields of maize in Northern Region. Extra-early (TZEE W STR QPM C0) and any of the early maturing maize varieties may be used due to the erratic nature and short duration of rainfall.

Table 7: Nitrogen rate and maize variety effect on grain and stover yield in Northern Region

	Grain yield (kg/ha)			Stover yield (kg/ha)		
N rate (kg/ha)	2014	2015	Mean	2014	2015	Mean
Recommended (60)	2452.0	2907.7	2679.9	3268.9	5559.1	4414.0
Higher (90)	3141.6	3803.2	3472.4	4037.8	6895.8	5466.8
SE	135.01	222.91	129.47	148.23	342.47	186.69
P-value	0.0056	0.0194	0.0019	0.0052	0.0221	0.0032
Variety (V)						
Abontem[ee]	2321.7	2687.5	2504.6	2886.7	5395.3	4141.0
TZEE W STR QPMCO[ee]	3168.1	3565.3	3366.7	4113.3	6817.3	5465.3
Abrohemaa[e]	2477.7	3353.1	2915.4	3193.3	5562.7	4378.0
Omankwa[e]	2934.3	3370.1	3152.2	3866.7	6127.3	4997.0
Obatanpa[m]	2750.5	3581.9	3166.2	3880.0	7211.3	5545.7
DT SR W C0 F2[m]	3128.60	3574.93	3351.77	3980.00	6250.67	5115.33
SESE	203.87	190.64	207.12	274.27	346.05	345.48
P-value	0.0188	0.0097	0.0347	0.01	0.0021	0.0206
Mean	2796.8b	3355.5a		3653.3b	6227.4a	

ee = extra early, e = early, m = medium; values with same letters are not significantly different.

2.1.2 Insecticide management for sustainable cowpea production in Northern Region

Cowpea is an important grain legume crop in West Africa, providing protein to supplement the nutritional needs of most households. Stover is a source of feed for livestock. Use of unimproved varieties by farmers and pest damage are causes of low yield on farmers' fields. The effect of spraying regime on grain yield of improved cowpea varieties was evaluated on-farm using a split-plot design replicated in five communities. Main plots were two spraying regimes (once and three times) during the cropping season which were selected based on results from earlier on-station trials. Sub-plots were six improved cowpea varieties (Songotra, Apagbaala, Padituya, IT 99 K 573-1-1, Zaayura, and a local check). Grain and fodder yields were measured.

The main effect of spraying regime affected grain yield, while variety affected fodder yield (Table 8). Year significantly affected both grain and fodder yield (Table 8). Spraying a cowpea crop with insecticides three times during the cropping season could be used to increase grain yield of improved cowpea varieties in Northern Ghana.

Table 8: Spraying regime and variety effect on cowpea grain and fodder yield in Northern Region

	Grain yield (kg/ha)			Fodder yield (kg/ha)		
Spray regime	2014	2015	Mean	2014	2015	Mean
Once	338.2	474.8	406.5	9038.9	11,241.1	10,140.0
Three times	521.2	784.4	652.8	9005.6	12,363.9	10,684.7
SE	6.95	52.38	25.30	1194.89	554.32	757.12
P-value	< .0001	0.0139	0.0023	ns	ns	ns
Variety (V)						
Songotra	405.7	569.5	487.6	5766.7	6816.7	6291.7
Apagbaala	327.7	716.8	522.3	8183.3	10,991.7	9587.5
Padituya	493.8	534.2	514.0	12,350.0	16,991.7	14,670.8
IT 99K 573-1-1	420.5	599.2	509.8	10,083.3	11,633.3	10,858.3
Zaaura	404.2	593.3	498.8	10,350.0	13,098.3	11,724.2
Local Check	526.17	764.50	645.33	7400.00	11,283.33	9341.67
SE	67.39	96.52	61.89	1101.42	1172.98	943.57
P-value	ns	ns	ns	0.0021	< .0001	< .0001
Mean	429.7b	629.6a		9022.2b	11802.5a	

ns = not significant at 0.05 and values with same letters are not significantly different.

2.1.3 Integrated soil fertility management for improved soybean production in Northern Region

Soybean is a newly introduced food and cash crop in Ghana. Grain yields on farmers' fields are low due to inappropriate soil fertility management practices.

The effect of integrated soil fertility management (ISFM) practices on grain yields of soybean was evaluated using a split-plot design replicated in six communities. Main plots were two improved, non-shattering soybean varieties (Jenguma and TGX-1904-6F). Sub-plots comprised five ISFM practices (Farmer practice, Triple superphosphate [TSP] at 60 kg/ha, Fertizol [F, an organic fertilizer] at 4 t/ha, TSP + F, TSP + F + Boostxtra). Grain and fodder yields were measured.

The year × variety × ISFM interaction did not affect grain and fodder yields significantly, but the main effects of year, variety, and ISFM did (Table 9). A combination of TSP at 60 kg/ha, Fertisol at 4 t/ha, and Boostxtra may be used to increase grain and fodder yield of soybean production in Northern Region.

Table 9: Variety and ISFM practice effect on grain and fodder yield of soybean in Northern Region

	Grain yield (kg/ha)			Fodder yield (kg/ha)		
Variety (V)	2014	2015	Mean	2014	2015	Mean
Jenguma	1753.0	995.6	1374.3	3900.2	1951.6	2925.9
TGX-1904-6F	1687.0	1109.6	1398.3	3289.1	1848.4	2568.8
SESE	181.26	80.00	88.99	164.95	152.95	88.81
P-value	ns	ns	ns	0.0471	ns	0.0361
ISFM						
Farmer practice	1210.8	732.7	971.7	2616.9	1050.0	1833.4
TSP at 60 kg/ha	1695.8	1175.1	1435.4	3603.9	2307.8	2955.8
Fertisoil (F) at 4 t/ha	1688.8	890.1	1289.4	3676.6	1840.0	2758.3
TSP + F	2139.9	1202.2	1671.1	4275.2	2090.0	3182.6
TSP + F + Boostxtra	1864.9	1262.8	1563.8	3800.7	2212.2	3006.4
SE	110.57	112.44	141.97	219.39	129.49	180.33
P-value	< .0001	0.0066	0.0081	0.0001	< .0001	< .0001
Mean	1720.0a	1052.6b		3594.6a	1900.0b	

TSP = Triple Superphosphate, ns = not significant at 0.05 and values with same figures are not significantly different.

2.1.4 Phosphorus fertilizer and groundnut variety for improved grain production in Northern Region

Groundnut too is an important legume crop in Ghana, but limited access to improved varieties and inappropriate soil management practices are key constraints to improved yield on farmers' fields in Northern Region. The effect of phosphorous (P) fertilizer rate on grain yields of improved groundnut varieties was evaluated on-farm using a split-plot design replicated in four communities. Main plots were two P fertilizer rates (government's sector Ministry recommended: 60 kg/ha and a higher rate of 90 kg/ha P_2O_5). Sub-plots were five improved varieties (Chinese, Azivivi, Obolo, Manipinta, and Yenyawoso). Grain and fodder yields were measured.

The year × P × variety interaction effect was not significant for grain and fodder yields. Phosphorus rate and variety affected fodder yield while year affected both grain and fodder yield (Table 10). Phosphorus fertilizer applied at 90 kg/ha may be used to improve grain and fodder yield of improved groundnut varieties in Northern Region.

Table 10: Phosphorus (P) rate and variety effect on grain and fodder yields of groundnut in Northern Region

	Grain yield (kg/ha)			Fodder yield (kg/ha)		
P rate (kg/ha)	2014	2015	Mean	2014	2015	Mean
Recommended (60)	507.0	925.9	716.5	4018.8	10,617.2	7318.0
Higher (90)	794.8	911.4	853.1	4732.8	11,678.1	8205.5
SE	61.30	34.95	37.48	82.65	438.32	191.78
P-value	0.045	ns	ns	0.0088	ns	0.0467
Variety (V)						
Chinese	662.9	791.4	727.2	4554.7	12,046.9	8300.8
Azivivi	605.1	1184.4	894.7	4191.4	12,527.3	8359.4
Obolo	744.1	794.5	769.3	4414.1	6992.2	5703.1
Manipinta	494.1	1028.5	761.3	4765.6	11,476.6	8121.1
Yenyawso	748.4	794.5	771.5	3953.1	12,695.3	8324.2
SE	102.37	91.19	83.65	447.22	1067.05	608.55
P-value	ns	0.0141	ns	ns	0.0048	0.0113
Mean	650.9b	918.7a		4375.8b	11147.7a	

ns = not significant at 0.05 and values with same figures are not significantly different.

2.1.5 Evaluating agronomic options to intensify sesame production in Northern Region

Sesame is a major oilseed crop that has recently been introduced in Ghana. Little is known about good agronomic practices for cultivation in Northern Region. Hence, the two separate trials were conducted to evaluate the effect of different agronomic practices on performance of sesame.

The first trial evaluated the effect of planting time and spraying regime on yield on-farm using a split-plot design with three communities as replicates. Main plots were three planting times (mid-July, late July, and mid-August). Sub-plots were three spraying regimes (one, twice, and three times). Capsules per plant and grain yield were measured.

The year × planting time × spraying regime interaction was not significant for the number of capsules per plant and grain yield. Planting time affected grain yield while spraying regime and year affected both number of capsules per plant and grain yield (Table 11). Applying insecticide three times during the cropping season to control pests may be used to improved production of sesame in Northern Region.

Table 11: Effect of planting time and spraying regime on number of capsules and grain yield of sesame in Northern Region

	Capsules (number/plant)			Grain yield (kg/ha)		
Planting Period	2014	2015	Mean	2014	2015	Mean
Mid-July	36.4	37.1	36.8	44.6	265.6	155.1
Late-July	39.0	31.4	35.2	55.0	164.9	110.0
Mid-August	41.5	18.7	30.1	58.3	133.7	96.0
Standard error	6.71	3.25	3.74	6.64	17.22	10.77
P-value	ns	0.0368	ns	ns	0.0123	0.0077
Spraying regime						
Once	33.2	23.8	28.5	32.8	142.4	87.6
Twice	37.7	27.6	32.6	55.9	166.7	111.3
Three times	46.0	35.7	40.9	69.3	255.2	162.2
Standard error	0.87	2.36	1.26	3.70	30.25	15.24
P-value	< .0001	0.0115	< .0001	< .0001	0.051	0.0065
Mean	40.0a	29.1b		52.7b	188.1a	

ns = not significant at 0.05 and values with same figures are not significantly different.

2.1.6 Rice variety responses to nitrogen fertilizer in Upper East Region

A factorial treatment of five fertilizer rates × two rice varieties arranged in a randomized complete block design to determine grain yield responses of an improved rice variety (Gbawee) and a farmers' variety continued for the second year in three locations in the Upper East Region. The fertilizer was applied as urea in two equal doses at planting and six weeks thereafter. Triple superphosphate (60 kg/ha P_2O_5) and muriate of potash (30 kg/ha K_2O) were applied at planting.

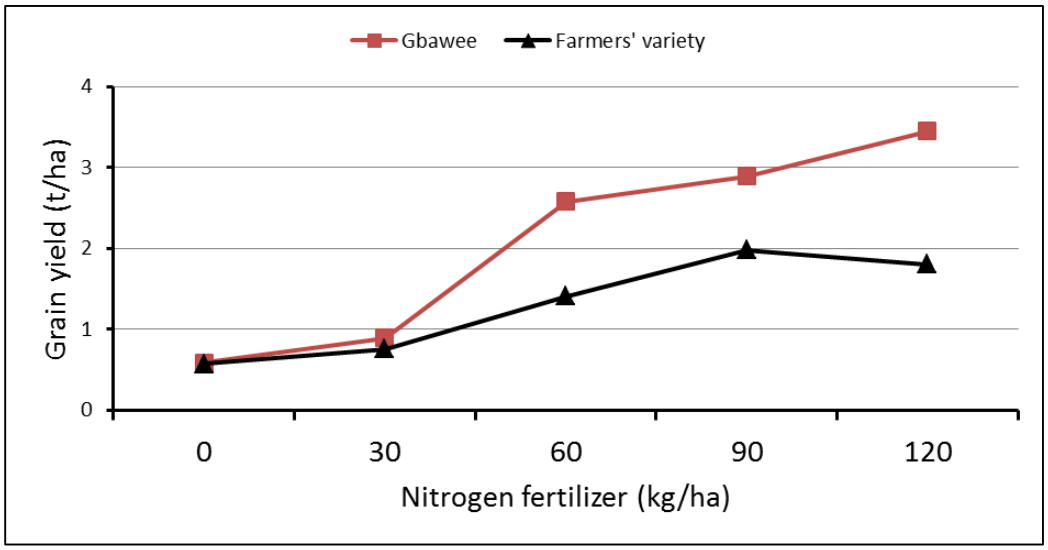

Figure 4: Grain yield responses of improved and farmers' rice varieties to nitrogen fertilizer (values are means of three locations)

Grain yield of the improved variety was generally higher than of the farmers' variety (Fig. 4). The grain yield of the improved variety showed a linear ($Y = -0.244 + 0.774x$; $r^2 = 0.91$) response with increasing N fertilizer rate, whilst that of the farmer variety was non-linear ($Y = 0.21 + 0.7161x - 0.0579x^2$; $r^2 = 0.92$).

2.2 Intensifying cereal-legume-vegetable cropping systems in Mali

2.2.1 Impact of improved management practices on fruit vegetable production

Fruit yields of okra and tomato varieties under improved and farmer standard practices in the dry season were compared in Mali. There was significant variety × management interaction for both species (Table 12). Fruit yield in Koutiala was generally higher than in Bougouni.

Table 12: Fruit yield of okra and tomato varieties under improved and farmer managed conditions

		Bougouni		Koutiala	
Species	Variety	Improved	Farmer	Improved	Farmer
Okra	Koni	3.4	4.7	6.3	6.2
	Batoumabe	2.8	2.9	9.9	9.8
	Local	4.3	2.5	5.4	5.4
	LSD ($P < 0.05$)	1.09		1.28	
Tomato	Rio Grande	23.4	14.8	37.6	34.1
	Roma	12.1	22.3	37.1	38.1
	Local	13.8	11.2	24.8	25.6
	LSD ($P < 0.05$)	2.45		4.73	

2.2.2 Agroforestry options for intensive fruit, vegetable, and fodder production in Mali

Studies on agroforestry options for intensive fruit, vegetable, and fodder production continued in Mali. As shown in Table 13, height, diameter, and canopy width differed significantly among 12 accessions of four indigenous tree species (*Adansonia digitata*, *Tamarindus indica*, *Vitellaria paradoxa*, and *Ziziphus mauritiana*) planted in 2013.

Grafted and non-grafted plants of *A. digitata and V. paradoxa* differed significantly in height and survival rate (Table 14). The collar diameter, height, canopy width, and survival rate differed significantly among the species. Grafted and non-grafted provenances of *T. indica* and *Z. mauritiana* also differed significantly in collar diameter, height, canopy width, and survival rate (Table 15).

The effect of spacing on leafy vegetable production from *A. digitata* and *Moringa oleifera* is presented in Table 16. The species varied significantly in canopy width and biomass production. Biomass production declined with increasing plant spacing, and varied with location.

Table 13: Growth of elite accessions of *Adansonia digitata*, *Tamarindus indica*, *Vitellaria paradoxa*, and *Ziziphus mauritiana* 17 months after planting, Koutiala, Mali

Accession	Height (cm)	Diameter (mm)	Canopy width (cm)
AD-Nonokene	68.1±8.5c	37.7±4.7a	23.3±9.4d
TI-Gros-fruit	93.4±8.3bc	24.9±2.8ab	52.8±9.4cd
TI-Niger-309	63.6±6.8c	18.9±1.8bc	57.3±5.9cd
TI-Sucré	88.0±7.6bc	19.1±1.7bc	66.8±7.8bc
VP-Samankoka	23.6±2.5d	13.6±1.0bc	23.4±3.0d
ZM-3A	128.3±18.8ab	24.8±4.2ab	90.5±13.6abc
ZM-Ben-Gurion	142.7±18.1ab	23.6±3.2abc	106.3±13.7ab
ZM-Gola	163.7±19.8a	22.9±3.1bc	115.6±14.6ab
ZM-ICRAF-06	222.5±17.3a	25.4±3.6abc	173.8±21.3a
ZM-ICRAF-08	100.2±13.5bc	14.8±2.1c	71.4±12.7bc
ZM-Kaithely	145.7±18.1ab	26.6±4.1abc	115.4±19.5ab
ZM-Umran	124.2±12.8ab	19.3±3.0bc	75.4±12.0bc

Means in a column with different letter(s) differ ($P < 0.05$).

Table 14: Growth and survival rate of grafted and non-grafted plants of indigenous fruit trees, Mali

	Height (cm)	Diameter (mm)	Canopy width (cm)	Survival rate (%)
Species				
Adansonia digitata	54.7±3.6a	16.3±1.4a	2.4±1.0b	100
Vitellaria paradoxa	17.5±1.9b	11.3±1.2b	20.5±3.6a	65
Grafting				
Grafted	45.9±5.9a	13.3±1.0a	10.3±3.2a	90
Non-grafted	33.0±4.6b	15.5±2.0a	8.6±3.0a	75

Means in a column with different letter(s) differ ($P < 0.05$).

Table 15: Growth and survival rate of grafted and non-grafted accessions of fruit trees, Mali

Accession	Height (cm)	Diameter (mm)	Canopy width (cm)	Survival rate (%)
Tamarindus indica				
TI-Gros-fruit	24.7±3.3b	6.0±0.4b	9.7±0.9b	90
TI-Niger-309	40.6±4.3a	9.2±0.5a	20.6±4.1a	80
TI-Non-grafted	43.5±3.4a	6.7±0.4b	17.3±2.3ab	100
TI-Sucré	30.6±3.5ab	7.3±0.5b	14.5±2.1ab	90
Ziziphus mauritiana				
ZM-3A	58.3±8.8abc	11.8±3.0a	26.9±7.2a	40
ZM-Ben-Gurion	54.1±10.4abc	9.9±1.a	37.1±7.0a	70
ZM-Gola	63.3±4.5ab	10.8±0.4a	36.8±2.1a	100
ZM-ICRAF08	27.8±11.1c	8.0±0.8a	11.7±4.9a	60
ZM-non-grafted	36.1±3.2bc	9.3±0.7a	21.9±23.0a	80
ZM-Umran	73.6±10.5a	8.2±1.1a	27.5±2.7a	50

Means in a column with different letter(s) differ ($P < 0.05$).

Table 16: Tree species, spacing, and location effects on collar diameter, canopy with and biomass, Mali

	Diameter (mm)	Canopy width (cm)	Biomass (kg)
Species			
Baobab *(Adansonia digitata)*	5.3±0.9a	11.1±1.3b	0.12±0.02b
Moringa *(Moringa oleifera*)	15.2±3.1a	61±7.86a	2.22±0.83a
Spacing			
30 cm	11.0±3.2a	40.8±13.9a	2.42±1.32a
50 cm	11.0±4.3a	37.0±13.0a	0.97±0.50a
100 cm	11.2±4.5a	42.0±13.1a	0.44±0.25b
Village			
Mpessoba	5.4±1.2a	14.1±3.54a	0.12±0.03b
Ngolonianasso	24.3±5.8a	78.5±5.07a	4.27±2.47a
Sirakele	9.0±1.7a	34.8±9.0a	0.54±0.34b
Zanzoni	10.7±4.4a	46.6±16.6a	1.55±0.84ab

2.3 Intensive livestock and integrated crop–livestock production systems in Ghana

2.3.1 Feed and health options to intensify Guinea fowl production

Guinea fowl (*Numida meleagris*) are kept by smallholder farmers in West Africa for meat, eggs, and cash. Mortality of the young Guinea fowl (keets) under the traditional extensive management systems is high due to microbial infections that can be reduced by the use of *direct-feed microbial* (DFM), which can provide protection as a naturally developed commensal gastrointestinal tract microflora. In spite of the potential of DFM to improve survival of keets, there is little or no information on the potential of DFM for Guinea fowl in West Africa.
Two experiments were conducted to evaluate the effect of different regimes of administration of Rumen Enhancer 3 (RE3), a DFM, on growth and laying performance of Guinea fowl under intensive management. The first experiment evaluated the effect of different frequencies of supplementing the DFM to keets from 1 to 56 days on growth performance and health status. The second trial evaluated the frequency of supplementing DFM at a rate of 1.5 ml/l of water on laying performance and health status of the keets from 9 to 30 weeks.

As shown in Table 17, keets supplemented with DFM at 1.5 ml/l of water daily had significantly higher final body weight than those on the other treatments. Daily feeding of DFM resulted in 57% more profit per bird and 2.5% lower mortality than the control. In experiment 2, supplementation of DFM significantly reduced feed intake, promoted faster growth rates, and gave heavier birds and eggs at first laying (Table 17). Results of the two experiments show that supplementing growing keets and laying birds with DFM at 1.5 ml/l of water daily can result in faster growth, better feed conversion ratio, and heavier birds and eggs at first laying.

Table 17: Direct-fed microbial diet effect on growth, blood chemistry, mortality, and profitability of guinea fowl keets from day 1 to 72 days

	Direct-fed microbial treatment[b]					
Parameter	Control	DFM-1D	DFM-3DW	DFM-7DW	SEM	*P*-Value
Growth performance						
Initial body weight/bird (g)	28.3	28.7	28.8	28.9	0.2	0.139
Final body weight/bird (g)	374.4	438.5	387.8	365.8	16.0	0.033
Average daily gain/bird (g)	5.5	7.0	6.0	5.3	0.8	0.435
Average daily feed intake/bird (g)	33.4	28.3	31.4	32.6	4.5	0.864
Feed conversion ratio	6.5	4.1	5.8	8.7	1.1	0.040
Mortality (%)	3.6	1.4	2.8	2.5	0.9	0.433
Serum biochemistry						
Albumin (g/l)	15.62	17.00	16.32	16.40	0.10	0.809
Globulin (g/l)	17.89	22.73	21.83	20.32	1.65	0.251
Total protein (g/l)	33.48	39.75	38.18	36.72	2.46	0.376
Total cholesterol (mmol/l)	3.92	4.85	4.81	4.78	0.26	0.104
Triglycerides(mmol/l)	1.04	1.31	1.41	1.37	0.15	0.387
Profit (US$/bird)	0.71	1.12	1.02	0.90		

Control: no direct-fed microbial (DFM).

DFM-1D: direct fed microbial through water at 1.5 ml/l daily.

DFM-3DW: direct fed microbial fed through water at 1.5 ml/l on 3 consecutive days per week.

DFM-7DW: direct fed microbial fed through water at 1.5 ml/l for 7 consecutive days per week every other week.

Table 18: Direct-fed microbial diet effect on laying performance and health of Guinea fowl

	Direct-fed microbial treatment[b]					
Parameter	Control	DFM-1D	DFM-3DW	DFM-7DW	SEM	*P*-Value
Growth performance						
Average daily feed intake/bird (g)	76.5	70.7	73.6	75.7	0.9	0.007
Final body weight/bird (g)	1178.9	1354.7	1196.4	1184.6	40.6	0.044
Average daily gain/bird (g)	6.4	7.9	6.8	6.2	0.3	0.009
Average daily feed intake/bird (g)	33.4	28.3	31.4	32.6	4.5	0.864
Feed conversion ratio	7.3	4.4	6.2	6.2	0.8	0.147
Mortality (%)	13.9	5.6	8.3	11.1	5.4	0.728
Egg characteristics						
Age of bird at first egg (days)	120.0	116.7	121.0	127.7	3.67	0.269
Weight of bird at first egg (g)	849.7	964.0	846.7	829.1	22.33	0.010
Weight of first egg laid (g)	21.0	27.0	23.0	23.3	1.20	0.043
Egg weight (g)	31.4	35.6	32.4	32.8	0.30	<.0001
Albumen weight (g)	50.9	18.1	17.0	17.0	0.77	0.352
Yolk weight (g)	8.8	8.9	9.4	8.5	0.40	0.513
Egg shell weight (g)	5.4	5.1	6.0	5.4	0.24	0.123
Carcass characteristics (g/bird)						
Live weight	1116.8	1338.5	1188.0	1158.3	45.3	0.038
Bled weight	1075.2	1273.5	1146	1113.5	51.4	0.108
Defeathered weight	1009	1179.5	1045.8	1023	46.2	0.103
Dress weight	834.2	947.8	904.2	854.2	33.9	0.156
Shank weight	24.0	27.1	26.8	24.7	0.6	0.017
Neck weight	40.8	52.5	51.8	44.2	2.4	0.022
Serum biochemistry						
Albumin (g/l)	18.7	23.6	18.9	18.5	1.06	0.024
Globulins(g/l)	25.1	32.6	25.7	23.4	2.73	0.166
Total Protein (g/l)	43.8	56.3	44.5	41.9	3.74	0.092
Cholesterol (mmol/l)	7.3	4.2	4.5	5.9	0.84	0.103
Triglycerides (mmol/l)	1.3	1.1	1.9	2.8	0.77	0.449

[b]Control: no direct-fed microbial (DFM).

DFM-1D: direct fed microbial through water at 1.5 ml/l daily.

DFM-3DW: direct fed microbial fed through water at 1.5 ml/l on 3 consecutive days per week.

DFM-7DW: direct fed microbial fed through water at 1.5 ml/l for 7 consecutive days per week every other week.

2.3.2 Small ruminant stocking rate effects on grain yield, soil characteristics, and vegetation dynamics

Second year data collection for a study to evaluate the effect of a combination of different intensification levels of sheep and goat stocking density (0, 400, and 200 heads/ha) on farmland overnight (corralling), maize planting density (6.93, 10.40, and 138.67 × 10^3 plants/ha), and nitrogen fertilizer rate (0, 60, 90 kg/ha N) on crop productivity, soil properties (chemical, physical, and biological) and vegetation (seed numbers and species diversity) using a split-split plot design with nine replications in three communities (Gia, Nyangua, and Samboligo) in Navrongo District in Upper East Region was completed. Data was computerized and analysed. Some results are presented in Tables 19–23.

Table 19: Sheep and goat stocking density on fallow land before planting maize on changes in soil chemical characteristics, Navrongo, Upper East Region

Sheep & goat stocking density (heads/ha)	pH (1:1 H_2O)			OC (g/kg)			TN (g/kg)		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
0 (Control)	5.1	5.4	5.2	7.3	10.8	9.1	0.4	0.6	0.5
70 (Low)	5.4	5.8	5.6	12.3	13.9	13.1	0.5	0.8	0.7
140 (High)	5.5	5.8	5.6	15.0	16.8	15.9	0.6	0.9	0.8
SE	0.05	0.12	0.06	0.69	0.61	0.46	0.02	0.05	0.04
P-value	***	*	***	***	***	***	**	**	**
Mean	5.3b	5.6a		11.5b	13.9a		0.5b	0.8a	

*= significant at 0.05, **= significant at 0.01, ***= significant at < 0.001 and values with different letters are significantly different; OC = organic carbon; TN = total nitrogen.

Table 20: Sheep and goat stocking density on fallow land before planting maize effects on soil physical characteristics, Navrongo, Upper East Region

Sheep and goat stocking density (heads/ha)	Bulk density (g/cm^3)	Porosity (%)	Moisture (cm^3/cm^3)
0 (Control)	1.5	0.5	0.03
70 (Low)	1.6	0.4	0.03
140 (High)	1.7	0.4	0.02
SE	0.01	0.01	0.003
P-value	< .0001	< .0001	ns

Table 21: Sheep and goat stocking density on fallow land before planting maize effects on soil biological characteristics, Navrongo, Upper East Region

Sheep and goat stocking density (heads/ha)	MBC (mg/kg)			MBN (mg/kg)			SMQ (%)		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
0 (Control)	241.9	260.0	250.9	18.7	22.9	20.8	2.7	2.5	2.6
70 (Low)	328.9	358.7	343.8	21.8	26.3	24.0	3.1	2.9	3.0
140 (High)	352.5	384.8	368.6	21.2	26.9	24.1	3.1	2.8	3.0
SE	14.27	10.80	9.09	0.80	0.52	0.54	0.08	0.07	0.09
P-value	**	***	***	*	**	***	**	**	**
SE Mean	307.8b	334.5a		20.5b	25.4a		3.0a	2.7b	

MBC = microbial biomass carbon, MBN = microbial biomass nitrogen, SQM = soil microbial quotient, *= significant at 0.05, **= significant at 0.01, ***= significant at < 0.001 and values with different letters are significantly different.

The density of small ruminants corralled on farm lands overnight in integrated crop–livestock systems significantly affected the soil chemical (Table 19), physical (Table 20), and biological (Table 21) properties as well as the weed diversity and frequency (Table 22).

Maize grain yield and total biomass increased as the density of small ruminants on the farmland overnight and nitrogen fertilizer rate increased (Table 23). The cob size declined with increasing maize planting density, but increased as the nitrogen fertilizer rate increased (Table 24).

Increasing the stocking rate of sheep and goats on the fallow land before planting increased soil pH, organic carbon and total nitrogen (Table 19), bulk density and porosity (Table 20), microbial biomass carbon, microbial biomass nitrogen, and microbial biomass quotient (Table 21) as well as the weed dynamics in the maize production system (Table 22). Grain and biomass yields also increased in response to increasing sheep and goat stocking density and nitrogen fertilizer rates (Table 23).

Cob size declined, whilst grain yield increased with increasing maize planting density (Table 24). Both cob size and grain yield increased in response to increasing nitrogen fertilizer rates.

The above results on the interactions between livestock, planting density, and nitrogen fertilizer rate demonstrate the need for multidisciplinary research in testing combinations of technologies for sustainable intensification of the smallholder production systems. The results stress the key role of livestock in improving productivity and affecting agrobiodiversity and soil physical, chemical, and biological properties in integrated crop–livestock systems.

Table 22: Sheep and goats stocking density on fallow land before planting maize and nitrogen fertilizer rates effect on soil weed biological characteristics, Navrongo, Upper East Region

	Stocking density (heads/ha)								
	0	70	140	0	70	140	0	70	140
Genus and species	2014			2015			Mean		
Broadleaf	**59.3**	**54.8**	**55.0**	**58.8**	**54.0**	**49.0**	**57.9**	**51.8**	**50.3**
Acanthospermum hispidum	–	0.8	1.5	–	1.6	1.4	–	2.1	2.2
Aspilia busei	4.0	3.4	4.8	3.6	5.3	4.6	4.2	3.7	3.8
Corchorus olittorius	9.7	8.3	8.8	10.9	7.5	6.6	7.4	5.4	5.3
Commelina benghalensis	8.3	7.2	7.4	7.9	6.4	5.3	6.3	4.9	4.6
Crotalaria retusa	2.9	0.9	1.6	3.0	2.2	1.7	3.8	2.3	2.3
Desmodium triflorium	6.7	4.7	4.6	6.7	4.3	4.0	5.6	3.7	3.6
Diodia sarmentosa	5.8	6.2	3.0	7.0	5.5	4.4	5.5	4.4	3.3
Euphobia hirta	0.9	0.8	2.3	1.0	1.3	1.4	2.7	2.0	2.4
Hyptis spicigera	2.0	1.5	1.6	1.6	1.3	1.2	3.2	2.2	2.1
Ipomoea triloba	2.7	4.3	3.6	2.6	3.8	3.6	3.6	3.5	3.3
Laportea aestuans	–	1.0	0.6	–	0.6	1.0	–	1.9	1.9
Mitracarpus villosus	8.5	7.4	5.5	6.1	6.4	4.4	5.9	4.9	3.9
Oldenlandia corymbosa	5.7	4.4	5.1	5.5	4.3	5.7	5.1	3.7	4.2
Phyllanthus amarus	–	1.2	2.7	1.0	1.7	2.9	1.4	2.2	2.9
Polycarpaea corymbosa	–	0.6	0.7		0.5	0.6	–	1.8	1.8
Sesamum indicum	2.0	1.5	0.6	1.9	1.3	0.4	3.2	2.2	1.7
Striga hermonthica	–	0.7	0.7	–	–	–	–	0.9	0.9
Grass	**19.1**	**24.2**	**20.9**	**22.4**	**26.7**	**29.0**	**25.1**	**30.6**	**30.9**
Andropogon tectorum	–	1.8	2.5	0.9	1.9	1.8	1.4	2.4	2.5
Brachiaria lata	–	2.2	1.5	1.8	2.1	1.8	1.6	2.6	2.3
Dactyloctenium aegyptium	–	0.8	1.8	1.0	2.2	3.0	1.4	2.2	2.7
Digitaria gayana	–	–	0.7	–	–	0.8	–	–	1.8
Digitria horizontalis	5.6	3.6	3.5	5.2	5.0	4.8	5.0	3.6	3.6
Echinochloa colona	–	1.4	1.0	–	1.9	3.5	–	2.3	2.6
Hackelochloa granularies	2.4	4.6	3.6	4.4	4.3	4.3	4.0	3.7	3.4
Panicum maximum	–	0.8	0.8	–	0.7	1.1	–	1.9	1.9
Paspalum scrobiculatum	7.1	3.1	2.3	5.6	2.9	1.6	5.5	3.0	2.4
Pennisetum pedicellatum	–	0.7	0.9	–	0.6	1.3	–	1.8	2.0
Sacciolepis africana	–	0.7	1.2	–	1.1	1.0	–	1.9	2.0
Setaria barbata	1.5	1.5	1.3	0.8	2.0	2.1	2.9	2.4	2.3
Setaria pumila	2.4	3.1	–	2.7	2.0	1.8	3.5	2.7	1.2
Sedge	**21.6**	**20.9**	**24.1**	**18.8**	**19.3**	**22.0**	**16.9**	**17.5**	**18.9**
Cyperus difformis	–	0.6	0.6	–	1.7	1.6	–	2.1	2.0
Cyperus esculentus	–	4.5	5.9	5.9	5.0	4.7	2.6	3.9	4.1
Cyperus rotundus	7.4	4.9	5.0	6.2	3.2	4.8	5.7	3.5	3.9
Fimbristylis littoralis	9.7	7.1	7.5	6.7	6.7	6.3	6.4	4.9	4.9
Mariscus alternifolius	4.5	3.9	5.1	–	2.7	4.6	2.3	3.1	3.9

Table 23: Sheep and goats stocking density on fallow land before plant maize and nitrogen fertilizer rate effects on maize yield, Navrongo, Upper East Region

	Grain yield (kg/ha)			Biomass (kg/h)		
	N rate (kg/ha)			N rate (kg/ha)		
Sheep & goat density (heads/ha)	0	60	90	0	60	90
0 (Control)	678	1285	1428	2879	5021	5461
70 (Recommended)	1242	2253	2675	4770	7218	8009
140 (High)	1409	2563	2856	5097	8063	8774
SE	66.5			136.7		
P-value	< .0001			0.0014		

Table 24: Sheep and goats stocking density on fallow land before planting maize and nitrogen fertilizer rate effects on maize yield, Navrongo, Upper East Region

	Cob size (cm)			Grain yield (kg/ha)		
	N rate (kg/ha)			N rate (kg/ha)		
Maize density (10^3plants/ha)	0	60	90	0	60	90
66.7 (Recommended)	160	212	226	901	1554	1917
100.0 (50% higher)	151	199	196	1164	2180	2319
133.3 (100% higher)	135	173	200	1263	2365	2723
SE	3.7			66.5		
P-value	0.0008			0.0012		

2.4 Improving land, soil, and water management in Mali

2.4.1 Watershed characterization and biophysical monitoring

Characterization and biophysical monitoring of watersheds continued during the reporting period. Preliminary data from the two technology parks showed that the area is characterized by unpredictable and insufficient rainfall due to climate variability or change. The small amount of rain falling in heavy storms is lost by runoff leading to erosion (Fig. 5). Preliminary data from the Technology Parks indicate that runoff rates varied between the treatment and control plots (Fig. 6). Though data is for only one agronomic season, the results suggest that water conservation is key for sustainable crop production in the studied region.

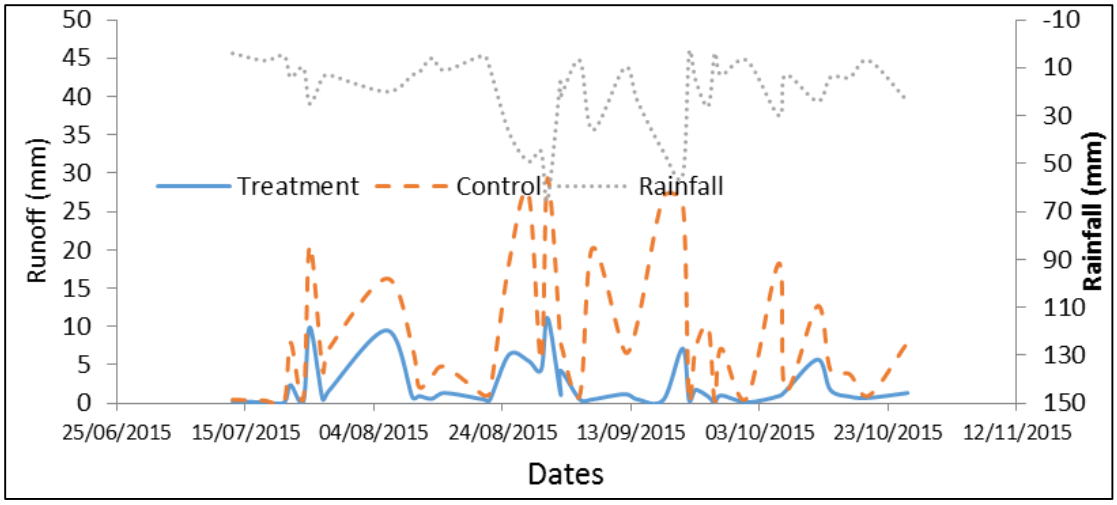

Figure 5a: Rainfall and runoff at Flola Technology Park (Bougouni)

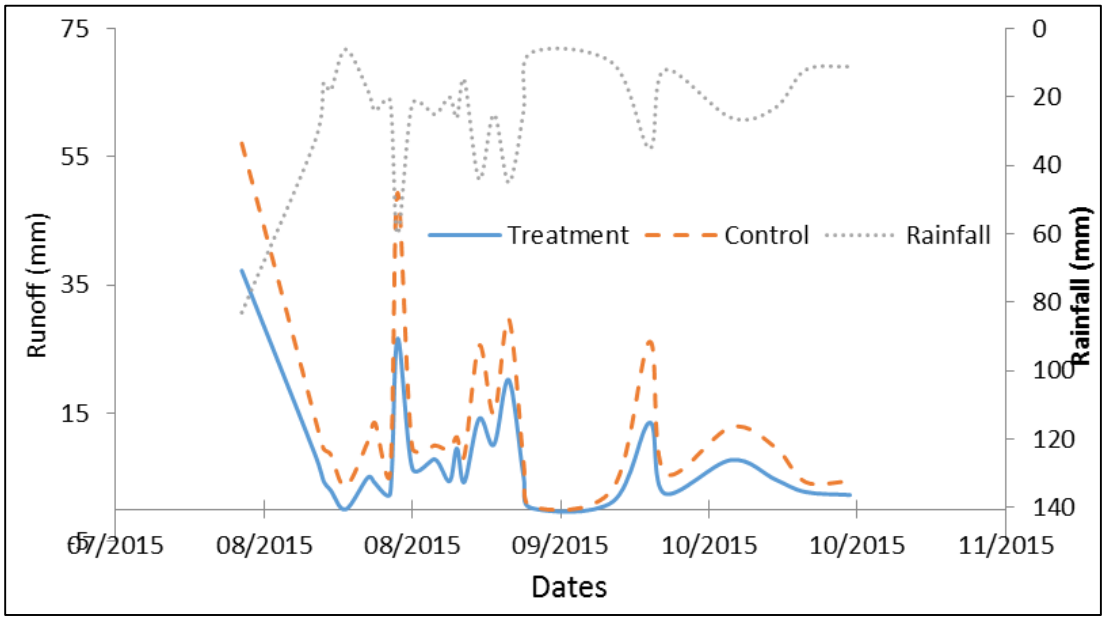

Figure 5b: Rainfall and runoff at M'Pessoba Technology Park (Koutiala)

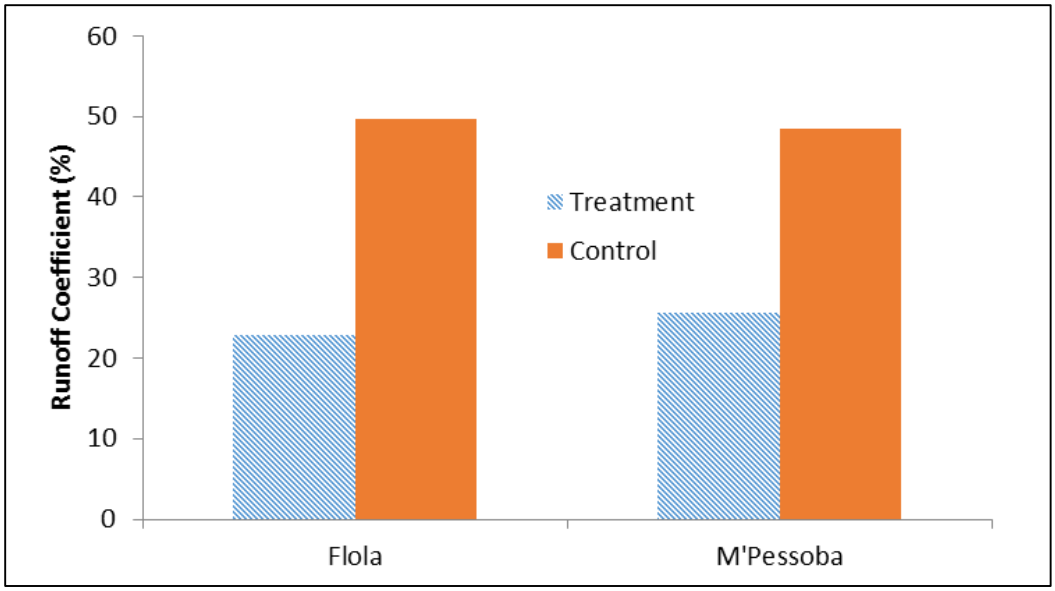

Figure 6: Runoff coefficient at Flola and M'Pessoba Technology Parks, Mali

Land use/land cover maps were prepared using Landsat 8 ETM imagery @30m resolution for the watersheds in Koutiala and Bougouni districts). In Koutiala, two watersheds Nampossela and N'Golonianosso, were smaller (5409 ha and 5857 ha) than the M'Pessoba and Zanzoni/Sirakela watersheds with an area of 13,953 ha and 15,394 ha, respectively (Fig. 7).

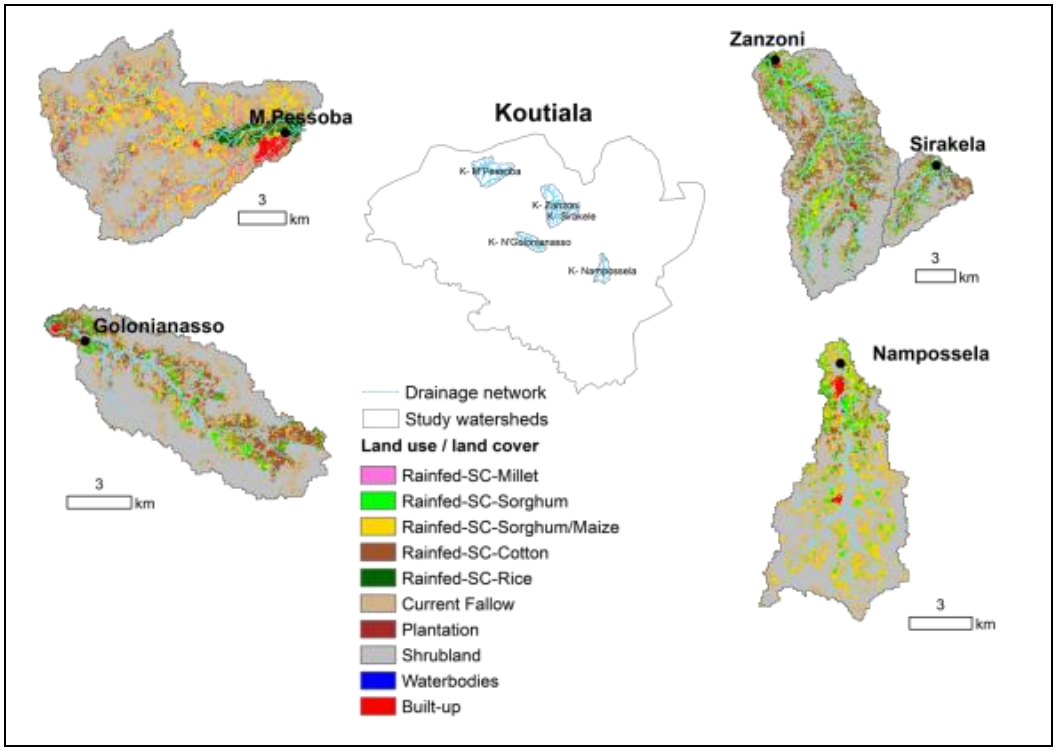

Figure 7: Land use/land cover in Koutiala watersheds, Mali (2013-14)

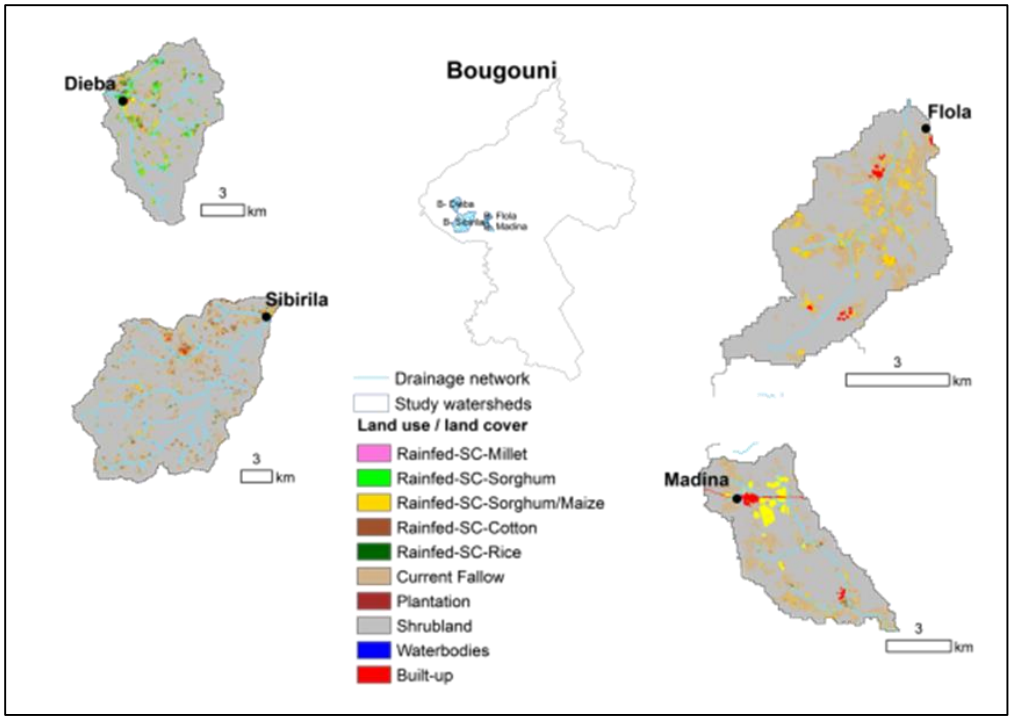

Figure 8: Land use/land cover in Bougouni watersheds, Mali (2013-14)

In Bougouni District (Fig. 8), the largest watershed identified was Sibirila with a total drainage area of 22,478 ha, the other three Flola, Madina, and Deiba being relatively very small with areas ranging from 2500 ha to 7000 ha. All the watersheds are dominated by shrubland covering more than 75% of the area.

2.4.2 Impact of adoption of NRM technologies

Watershed interventions in the upstream area and its effects downstream were assessed using temporal remote sensing imagery and a runoff model. A sub-watershed in Koutiala watershed villages was selected with a drainage area of 97,000 ha (Fig. 9). The area was subdivided into smaller upstream and downstream watersheds for monitoring the effects of interventions upon land use/land cover and runoff. Soil and water conservation measures were applied in the upstream smaller watersheds of Mpessoba and Ntiesso. Land use/land cover changes between 1990 and 2014 were studied to understand the impact of interventions in the selected upstream watersheds on the downstream watershed Fonfana (Fig. 10). Watersheds where interventions were not applied were also compared with the study watersheds which are being used as controls. This work is currently ongoing.

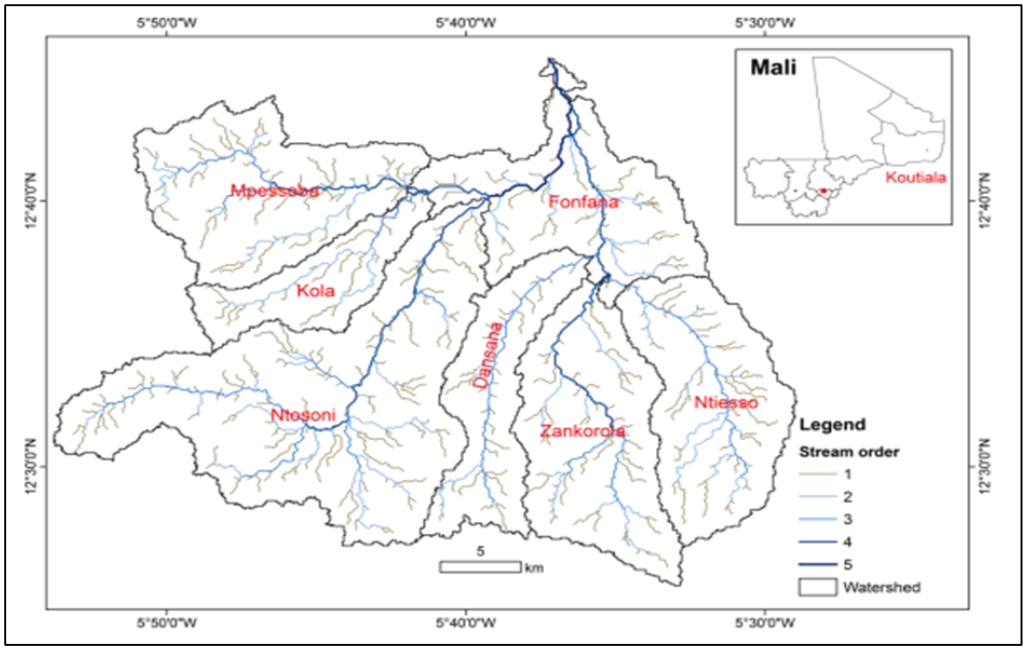

Figure 9: Watersheds selected to study impact of upstream intervention on water availability and irrigation in downstream

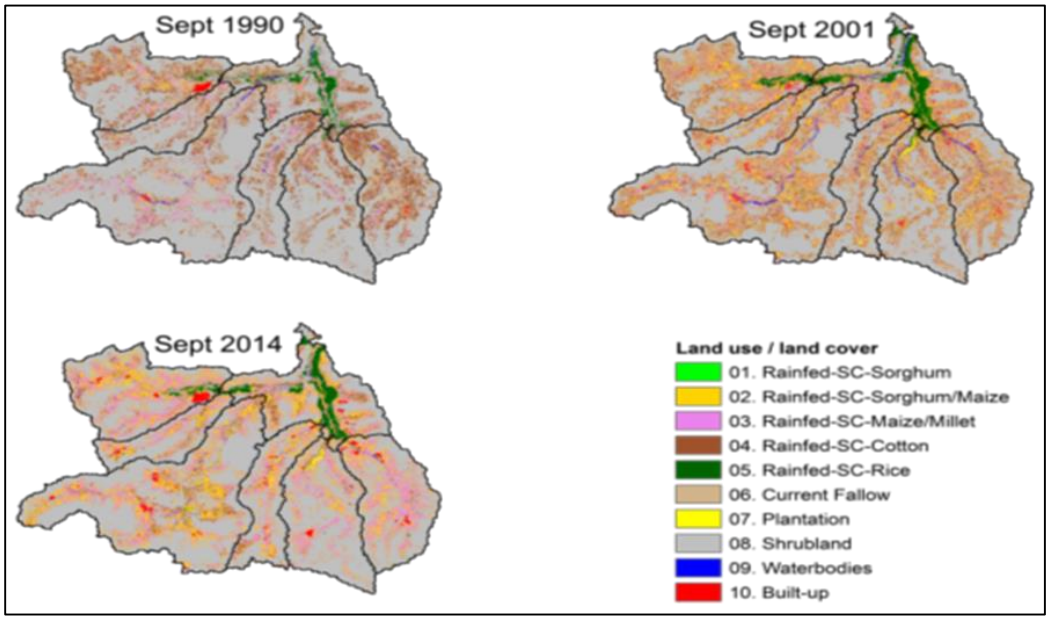

Figure 10: Temporal changes of watershed selected for impact study in Koutiala, Mali

2.5 Improving household nutritional diversity in Mali

2.5.1 Training of community and extension workers in Mali

Training on improved nutrition practices and evaluation of strategies for improving household nutritional diversity was organized. Four "training of trainers" were organized by AVRDC and AMEDD focusing on: timely introduction of complementary foods, optimal complementary feeding practices, food groups and nutrition needs of young children, hygiene during food preparation, handling and storage, nutrition needs of pregnant and lactating women, and essential nutrition action for young children and pregnant and lactating women. Upon return to their neighborhoods, the trainers were encouraged to share knowledge and information acquired to secondary beneficiaries. A total of 48 trainings were conducted for 2,828 women and 432 men.

2.5.2 Evaluation of dietary practices and nutrition status of children in Mali

A survey was conducted to obtain in depth information on nutrition status of young children, and dietary diversity scores of targeted households, women of child bearing age, and young children. A sample size of 120 pairs of women of child bearing age with their children aged 6–59 months were randomly selected among identified project beneficiaries in Sirakélé and Mpessoba. Baseline information of recruited infants and their mothers was collected using a structured questionnaire to elicit data on households, mother and infant characteristics, household, children, and mother dietary diversity practices, and anthropometrics measurements. The dietary diversity scores for the household and the respondents were estimated using information collected from the 24-hour dietary recall (FAO 2013: Guidelines for Measuring Household and Individual Dietary Diversity. FAO http://www.fao.org/3/a-i1983e.pdf) and food consumption score using information collected from 7 days (WFP 2008: Food Consumption analysis, Technical Guidance. WFP. http://documents.wfp.org/stellent/groups/public/documents/manual_guide_proced/wfp197216.pdf).

Qualitative food consumption score and household dietary diversity score (DDS) were used as household food security indicators. Nearly 77% of households have a medium or a high DDS (Fig. 11). Around 69% of household have good food consumption score (Fig. 12). The results suggest that more than 60% the targeted households have a high probability of being food secure and are able to access at least five food groups per day.

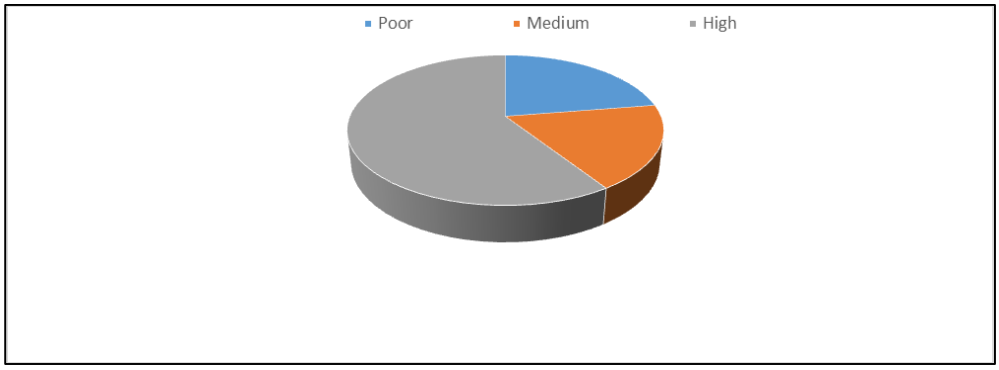

Figure 11: Household dietary diversity score

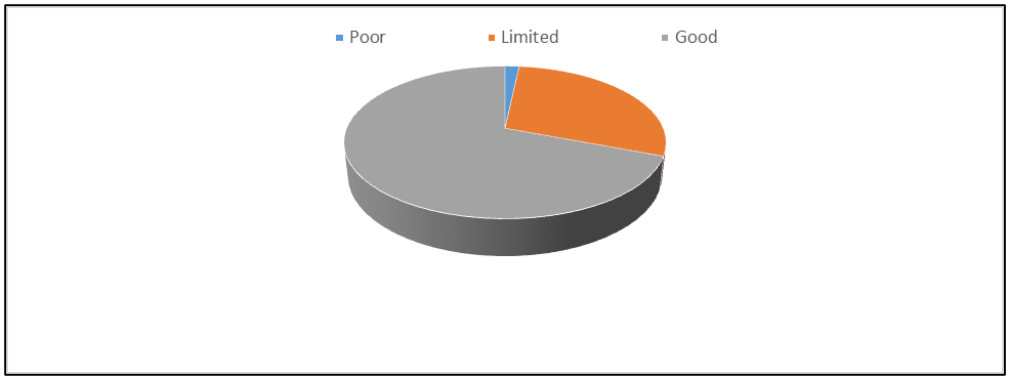

Figure 12: Household food consumption score

Women's and children's dietary diversity scores are shown in Figure 13. Overall women are consuming between one to six food groups on a scale of nine and children aged 6-23 months, one to four food groups on a scale of seven. Therefore, 96 % of children (Fig. 14) and 80 % of women (Fig. 15) exhibit a low DDS.

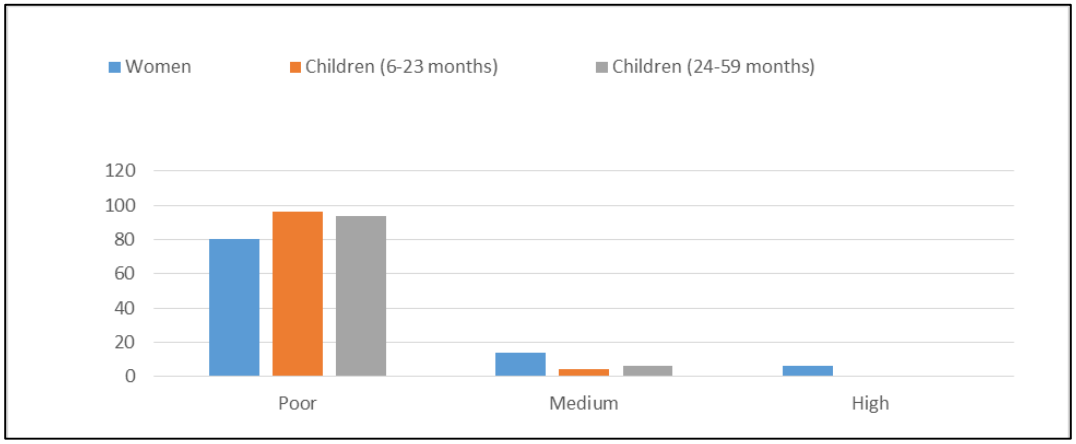

Figure 13: Women's and children's dietary diversity score

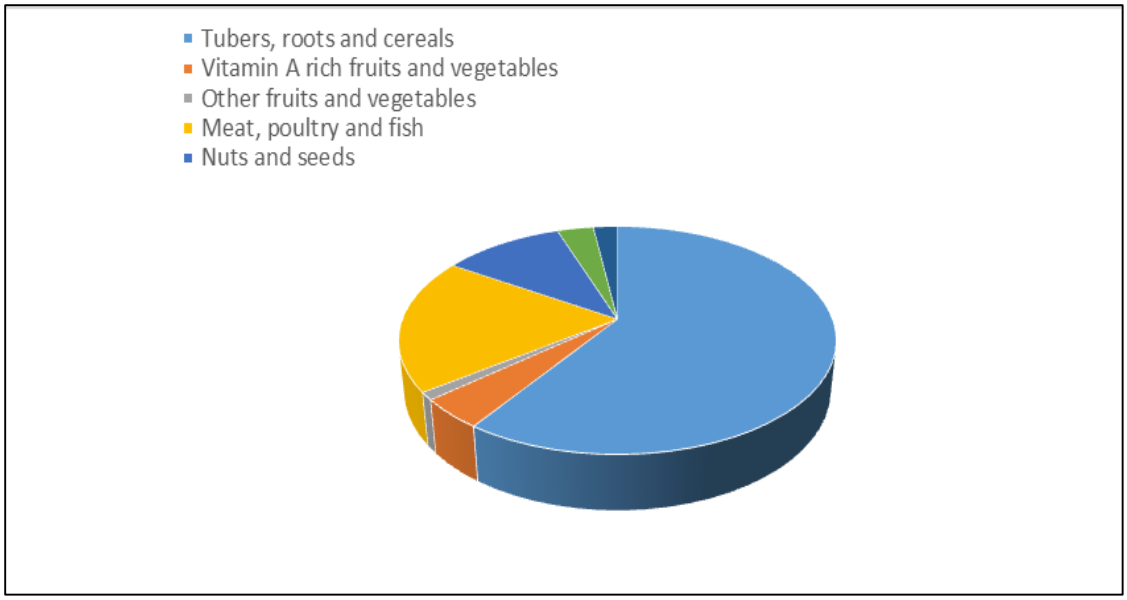

Figure 14: Food groups consumed by children aged 6-23 months

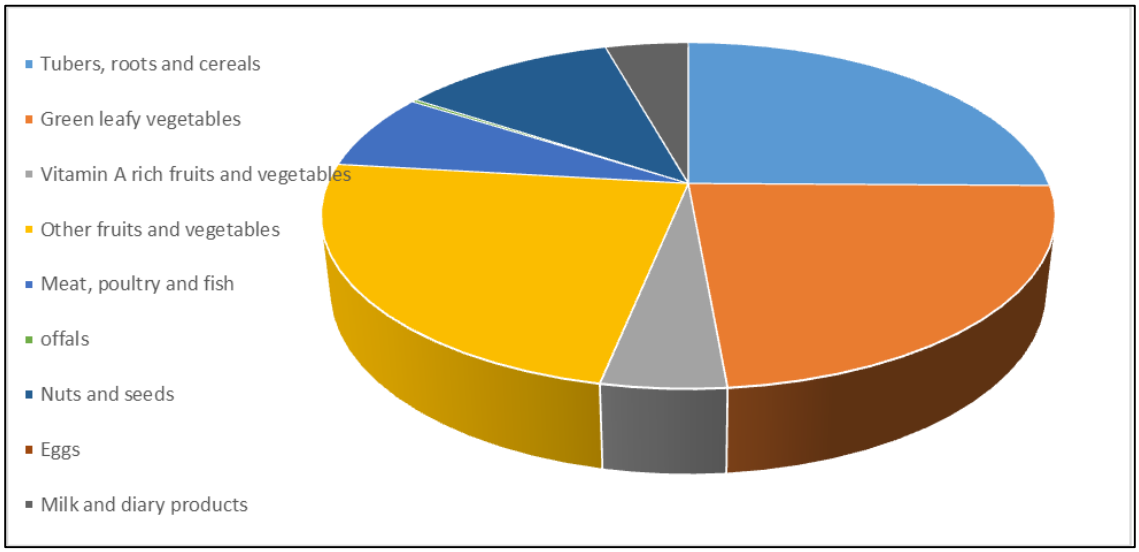

Figure 15: Food groups consumed by women

The main food groups consumed by women are cereals and tubers (98%), green leafy vegetables (90%), and seed and nuts (36%); while the main food groups consumed by young children are cereals and tubers (100%) and meat and fish (32%). Fruits and vegetables are consumed by only 9% of the targeted children.

The prevalence of malnutrition among children below 59 months of age is presented in Figure 16. Those aged 6–23 months are the most affected by wasting with a prevalence of 29% for those aged 6–11 months and 41% for those aged 12–23 months. This observation may be due to the consequence of poor weaning practices with the use of complementary foods not able to cover nutrient and energy requirements of fast growing children.

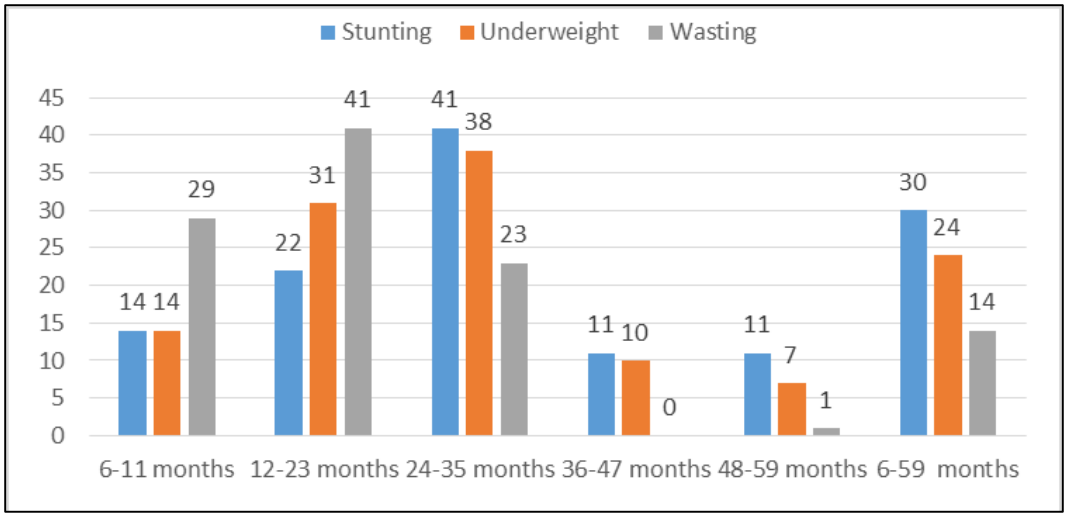

Figure 16: Prevalence of malnutrition among children in Mali

Although more than half of targeted households have a high probability of being food secure (at the time of the evaluation), more than 80% of children and women have a low DDS. Despite the fact that we cannot rule out the possibility of data errors or bias, these observations may suggest that a household's economic access to food is not always translated to improved quality of individual diets of household members, especially for women and young children. These observations should be confirmed by further studies. Furthermore, results of the Africa RISING Farm typology work conducted by IFPRI showed that Africa RISING beneficiaries are made of a heterogeneous population of farmers which may face different challenges and opportunities to adopt new technologies and probably behaviors. A better understanding of communities' and households' dynamics will help to alleviate factors or barriers which impede behavior change. Therefore, In addition to efforts aiming to improve year-long availability of nutritious foods, it is also important to focus on community mobilization to improve community and household nutrition practices as regards to children and women.

2.6 Aflatoxin biological control in Ghana

Two biocontrol products, aflasafe GH01 & aflasafe GH02, were developed. Each is formulated with four atoxigenic *Aspergillus flavus* strains native to Ghana that belong to vegetative compatibility groups (VCGs) widely distributed throughout Ghana and effective in reducing aflatoxin contamination in both maize and groundnut. aflasafe GH01 contains atoxigenic isolates belonging to VCGs that are distributed in one or more of the following countries: Benin, Burkina Faso, DRC, Ivory Coast, Kenya, Mozambique, Nigeria, Senegal, Tanzania, and Zambia; aflasafe GH01 is the first biopesticide containing atoxigenic genotypes native to more than one country, and is deliberately being promoted as a regional product or West Africa. aflasafe GH02 is a product containing atoxigenic isolates belonging to VCGs found only in Ghana as of now.

Two tons of aflasafe products (one ton each of aflasafe GH01 and aflasafe GH02) were produced by the IITA Aflasafe Manufacturing Plant for large-scale field efficacy trials and these trials were conducted in 240 maize and groundnut fields (approx. 90 ha) in Savelugu, Tolon, Bongo, Kassena-Nankana, Wa West, and Nadowli districts. In addition, a total of 120 maize fields (approx. 52 ha) were treated with aflasafe (GH01 or GH02) to conduct a carry-over experiment

aimed at determining the extent of carry-over of aflasafe strains from one season to the next and its cumulative impact on aflatoxin reduction 1 to 3 years after aflasafe application. Samples of maize and groundnut grains collected at harvest as well as samples of field soils collected before aflasafe application and three months after application from both efficacy and carry-over trials have been collected for aflatoxin and/or microbial analyses to generate efficacy data. Aflatoxin analyses revealed that several thousand tons of maize and groundnut produced from aflasafe treated fields contained at least 80% less aflatoxins in comparison to untreated (control) fields.

Regional aflatoxin awareness and sensitization campaigns were conducted and these resulted in increased awareness and knowledge on aflatoxins and its management. Over 300 maize and groundnut value chain participants attended these campaigns. Participants included farmers and farmer-based organizations from six districts, two each from the Northern, Upper East, and Upper West regions. Besides, key personnel from the Ministry of Food and Agriculture (MoFA), the public sector (The Ghana Export Promotion Authority), international agencies (The World Food Program), and development initiatives (SPRING Ghana) have been sensitized. These campaigns had the objective to sensitize participants on i) the prevalence of aflatoxin contamination in crops, ii) aflatoxins' health and economic importance to the citizenry, iii) aflatoxin management and use of aflasafe as a mitigation strategy, and iv) and potential opportunities to market grains harvested from aflasafe-treated fields. As a result of these campaigns aflatoxin awareness was increased and notable growing perception among stakeholders and regulators that biocontrol is a safe and effective technology for aflatoxin control in both maize and groundnut occurred.

Collaboration was established with national partners (KNUST, PPRSD, and MoFA) and regulatory authorities (EPA) for supporting awareness creation, movement of aflasafe products across borders, inspection of field efficacy trials, and strengthening national advocacy coalitions to facilitate the process of aflasafe registration. The Environmental Protection Agency (EPA) of Ghana was consulted on the registration process of aflasafe biopesticides in Ghana. EPA will inspect trials and provide guidance for going through the registration process.

3 Capacity building

Group and individual training were an integral part of project activities during the reporting period. In Mali, young scientists were trained for one week in statistical data analysis by a hired expert who also assisted the Africa RISING scientists in Mali with their data processing to facilitate publication of the research results.

A total of 20 graduate students (13 Masters and 7 PhD) were attached to the project for their dissertation research during the reporting period (Table 25).

4 Project implementation issues

Due to the late start of the rains, experiments on leaf stripping and use of cowpea as a “living-mulch” for maize production planned for the 2015 cropping season were not established.

The functioning of the R4D Platforms in Ghana without too much intervention by the project remains an issue. No meetings have taken place during the reporting period and initial momentum might get lost.
With the support from the Africa RISING Project in the Ethiopian Highlands, another training for the platform management teams is planned for May 2016.

The infrastructure for the dry-season vegetable hubs in Upper East Region in Ghana (i.e., fenced areas, water wells) could not be set up until at the end of January 2016. By that time, most seedlings in the nurseries were overgrown and big at transplanting time. This led to a low survival rate. In addition, the water wells dried out during the season due to extreme drought and had to be deepened. The water tanks in which the well water was pumped were too small to avoid frequent filling-up. The black colour of the tanks also resulted in water too hot for irrigation.

There needs to be better planning and coordination among the collaborating scientists to allow for timely planting in December. The water tanks need to be changed.

No activities were implemented in Ghana regarding improvement of maize shelling and drying using mechanical equipment. The equipment is available but there was no suitable staff to conduct field demonstrations. The initial idea was to get support from the Africa RISING postharvest team in Tanzania for the entire postharvest component of the program. However, this did not materialize due to their already high workload. No suitable national staff could be identified in time for the postharvest season.
The search process will continue not only for a specialist to demonstrate the mechanical equipment but also for a leader of the entire postharvest component.

The external evaluation of the Africa RISING Program in West Africa resulted in a preliminary report that suggested a series of recommendations to improve the project and ensure achievement of the expected goals. Most prominent were the need for more Technology Parks in Mali, the integration of livestock research in the Technology Parks, to enhance efforts on livestock systems improvement, the suspension of giving free inputs to farmers of baby trials to allow for assessment of willingness to adopt the technologies, better gender differentiated communication with the beneficiaries, and the strengthening of the R4D Platforms.

The project has discussed the recommendations and to the extent possible, started with their implementation.

5 Synergies with other USAID funded projects

5.1 Mali

5.1.1 Africa RISING's large-scale diffusion of technologies for sorghum and millet systems (ARDT_SMS)

The project is yet to hold its first Steering Committee Meeting, now planned for April 2016.

Achievements:
Objective 1: Enhance male and female farmers' knowledge of new sorghum and millet production technologies in selected Feed the Future (FtF) communities of Mopti and Sikasso regions, Mali

- 58 Training of Trainers (ToT) have been established in Mopti and in Sikasso regions
- 400 Farmer Field Schools were initiated by farmers' facilitators trained in ToT backed by field staff and reached 31,000 farmers
- 36,005 farmers have been trained in agricultural best practices based on proposed new technologies
- 176 extensionists were trained on good agricultural practices for both millet and sorghum
- 754 farmers were trained and became extensionists
- At least 36,000 farmers visited inputs fares
- 5,112 farmers were involved in study tours for exchanging knowledges
- In total, 23,847 ha were covered by improved technologies
- To increase the awareness of producers, the project trained radio presenters from seven rural partner radios to allow them to play their role in information dissemination of technologies related to millet and sorghum commodities

Objective 2: To facilitate male and female farmers' access to sorghum and pearl millet production technologies in order to strengthen the sorghum and millet value chains in the FTF target areas

The project made available 17 improved varieties of cowpea, sorghum, and millet. Forty-five tons of seeds were distributed to these farmers for scaling up the improved varieties. The distributed seeds have been treated with Apron Star. With our local partners based in Mopti and Sikasso, Société Générale d'Agrochimie (SOGEA) was able to procure Apron Star for local groups of farmers and for individual farmers.

5.1.2 Livestock Technology Scaling

The feed-health interventions package for improved small ruminant production developed by the Africa RISING project in Ghana is one of the livestock technologies to be scaled up by a new project funded by USAID Mali on Livestock Technology Scaling in three regions (Mopti, Sikasso, and Timbuktu) of Mali in 21 communes (local government areas) where the project is intervening. The USAID Mali Livestock Technology Scaling project led by ILRI started in January 2016 and the duration is 4 years. This is a success story of a technology developed by Africa RISING being adopted by another project to achieve impact at scale.

5.2 Burkina Faso

5.2.1 Sustainable Intensification Innovation Lab (SIIL)

A new project on sustainable intensification of crop–livestock systems in the Sahelian zone of Burkina Faso funded by Feed the Future Sustainable Intensification Innovation Lab (SIIL) capitalized on research outputs from Africa RISING in terms of tools and approaches for participatory testing and evaluation of sustainable intensification innovations. These tools and approaches (sustainability indicator framework, mother–baby approach for agronomic trials, nutrition home gardens to improve household food security and nutrition) will be used for on-farm testing and evaluation of sustainable intensification options under the SIIL Burkina Faso project.

5.3 Ghana

The Project Manager and the Chief Scientist visited the USAID Mission in Accra and Tamale in November 2015. A workshop was organized by the Africa RISING project for USAID-funded development projects in March 2016 to present Africa RISING and the validated technologies that could be out-scaled by the development projects. Representatives from the ATT, RING, SPRING, and ADVANCE projects participated in the workshop.

5.3.1 Agricultural Technology Transfer Project (ATT)

An MOU was signed with the ATT project on collaboration in maize, soybean, and rice technology development, support to the Savanna Agricultural Research Institute's (SARI) research efforts, and support to SARI's business management.
A representative of ATT participated in Africa RISING's annual review and planning meetings in March 2016.

5.3.2 Strengthening Partnerships, Results and Innovations in Nutrition Globally (SPRING)

A plan has been developed with the SPRING project to apply the Ghana specific aflatoxin biocontrol product Aflasafe to groundnut in 150 farmer field schools during the next field season.

5.3.3 Reduction of Post-Harvest Losses Innovation Lab (PHLIL)

The collaboration with Post-Harvest Losses Innovation Lab (PHLIL) with whom a MoU had been signed in October 2015 has encountered challenges. Africa RISING would like PHLIL to provide its own resources (staff time and funds) for joint activities as Africa RISING does not have sufficient manpower and local expertise in the area of postharvest. However, Ghana PHLIL has neither funds nor personnel to man a station on the ground. Collaboration between the two projects therefore appears to be not possible at the moment.

6 Selected publications and posters

6.1 Peer-reviewed journals

1. Birhanu Z and Tabo R, (2016). Shallow wells, the untapped resource with a potential to improve agriculture and food security in Southern Mali. Journal of Agriculture & Food Security (accepted).

2. Glover-Amengor, M, Agbemafle I, Hagan, L L, Mboom F P, Gamor G, Larbi A and Hoeschle-Zeledon I (2016). Nutritional status of children 0–59 months in selected intervention communities in northern Ghana from the Africa RISING project in 2012: Archives of Public Health (DOI: 10.1186/s13690-016-0124-1).

3. Kuivanen, K S, Michalscheck, M, Descheemaeker, K, Adjei-Naisah, S, Mellon-Bedi, S, Groot, J C J, Alvarez, S (2106). A comparison of statistical and participatory clustering of smallholder farming systems - A case study in Northern Ghana. Journal of Rural Studies (accepted).

4. Umutoni, C, Ayantunde, A and Sawadogo, G J 2015. Evaluation of feed resources in mixed crop-livestock systems in Sudano-Sahelian zone of Mali in West Africa. International Journal of Livestock Research, Volume 5:27-36.

5. Umutoni, C, Ayantunde, A, Turner, M and Sawadogo, G J (2016). Participation in decentralized natural resource management in Sudano-Sahelian zone of Mali. Environment and Natural Resources Research (accepted).

6.2 Posters presented at the 2016 review and planning meeting

1. Abdul Rahman N, Larbi A, Kotu B (2016). Starter nitrogen fertilization effect on yield and profitability of cowpea in northern Ghana. https://cgspace.cgiar.org/handle/10568/73269

2. Agbetiameh, D, Ortega-Beltran, Elzein, A, Atehnkeng J, Awuah, R T, Cotty, P J and Bandyopadhyay, R (2016). Biocontrol of Aflatoxins in Maize and Groundnuts with Aflasafe GH01 and Aflasafe GH02, two biopesticides developed for Ghana. https://cgspace.cgiar.org/handle/10568/73297

3. Ansah, T, Kadyampakeni, D, Shedrack, C and Abdul Rahman, N (2016). Comparative yield performance and fodder quality of Napier grass in Northern Ghana. https://cgspace.cgiar.org/handle/10568/73279

4. Badolo, F, Kotu, B, Zemadim, B (2016). Cost-Benefit analysis of crop trials under the Africa RISING project in Mali. https://cgspace.cgiar.org/handle/10568/73282

5. Binam, J N, Sogoba, B, Zemadim, B, Dembele, C, Bayoko, A and Diakite, A (2016). Stakeholder mapping, analysis and engagement in Southern Mali. https://cgspace.cgiar.org/handle/10568/73284

6. Kadyampakeni, D, Kizito, F, Larbi, A, Ghansah, B and Appoh, R (2016). Biophysical characterization of watersheds in Northern Ghana. https://cgspace.cgiar.org/handle/10568/73278

7. Kizito, F, Kadyampakeni, D, Larbi, A, Salifu, E and Abdul Rahman, N (2016). Water, land and soil management strategies to intensify cereal-legume farming systems in Northern Ghana. https://cgspace.cgiar.org/handle/10568/73280

8. Konlan, S P, Ayantunde, A A, Avornyo, F K, Addah, W and Dei, H K (2016). Opportunities of emerging feed market in Northern Ghana. https://cgspace.cgiar.org/handle/10568/73281

9. Kotu B, Abdul Rahman N, Larbi A, Akakpo D B, Asante M, Mellon S B, Hoeschle-Zeledon I (2016). Insecticide Spray Regime Effect on Cowpea Yield and Financial Returns in Northern Ghana. https://cgspace.cgiar.org/handle/10568/73267

10. Larbi A, Addul Rahman N, Kotu B, Hoeschle-Zeledon I, Akakpo D B and Mellon S B (2016). Nitrogen rate and varietal effect on maize yield and financial returns in Northern Ghana. https://cgspace.cgiar.org/handle/10568/73269

11. Larbi A, Addul Rahman N, Kotu B, Hoeschle-Zeledon I, Akakpo D B, Mellon S B (2016) Integrated Soil Fertility Management Effect on Financial Return and Yield of Soybean in Northern Ghana. https://cgspace.cgiar.org/handle/10568/73271

12. Larbi A, Addul Rahman N and Hoeschle-Zeledon I (2016). Strip Cropping Effect on Yield of Maize, Cowpea and Groundnut in Northern Ghana. https://cgspace.cgiar.org/handle/10568/73270

13. Ollenburger M, Descheemaeker, K, Crane, T and Giller, K (2016). Solution space for sustainable intensification in Bougouni. https://cgspace.cgiar.org/handle/10568/73273

14. Saaka, M and Oladele, J (2016). Household Food Insecurity Among Pregnant Women In IITA Project Communities of Northern Ghana. https://cgspace.cgiar.org/handle/10568/73272

15. Sarfo, G K, Larbi, A, Donkoh, A and Hamidu, J A (2016) Performance of indigenous guinea fowls (Numida meleagris) fed direct-fed microbial. https://cgspace.cgiar.org/handle/10568/73268

16. Sobgui, C M , Diarra, H, Coulibaly, P, Tignegre, J B and Tenkouano, A (2016). Evaluate strategies for improving household nutritional diversity in Mali. https://cgspace.cgiar.org/handle/10568/73277

17. Umutoni C and Ayantunde A (2016). Transhumant practices and its effects on natural resource management in the Sudano-Sahelian Zone of Mali. https://cgspace.cgiar.org/handle/10568/73287

18. Umutoni, C and Ayantunde A (2016). Local conventions governing natural resource management in Southern region of Mali. https://cgspace.cgiar.org/handle/10568/73286

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Table 25: Africa RISING Funded Graduate Students – West Africa (Update: April 2016)

S/N	Name	Sex	E-mail	Country	Degree	University	Start	End	Specialization
1.	Theodore E. Avukpor	M	Eyram4bukky@yahoo.com	Ghana	MSc	KNUST	2014	2016	Horticulture
2.	Mohammed Abdul Kadir	M	faked45@yahoo.com"	Ghana	MSc	KNUST	2014	2016	Horticulture
3.	Naaba Jonathan	M	naabajonanthan@yahoo.com	Ghana	MPhil	KNUST	2014	2016	Horticulture
4.	Shaibu Mellon	M	Sbmellon2005@gmail.com	Ghana	MSc	WUR	2014	2016	Agricultural Economics
5.	Daniel A Apalibe	M	danielawentemiapalibe@gmail.com	Ghana	MSc	UDS	2014	2015	Animal Production
6.	Xu Youfei	M	Youfei-xu@wur.nl	Mali	MSc	WUR	2013	2015	Agro-ecology
7.	Salim Dumbia	M		Mali	MSc	Katibugou	2015	2016	Natural Resources Manage.
8.	Iddi Abdul-Basiru Sanda	M	bashplus001@gmail.com	Ghana	MPhil	UDS	2015	2016	Soil and Water Manage.
9.	Mary Awuni	F	angelasaknab@yahoo.com	Ghana	MSc	UDS	2013	2016	Pig Nutrition
10.	Eliasu Salifu	M	Salifueliasu@gmail.com"	Ghana	MSc	KNUST	2014	2016	Agricultural Engineering
11.	Iddrisu Bashiru	M	Bantabillan@yahoo.co.uk"	Ghana	MSc	KNUST	2014	2016	Horticulture
12.	Bright Amponsah	M	amponsahbk36@gmail.com	Ghana	MSc	KNUST	2013	2016	Mono-gastric Nutrition
13.	Martha Agyria	F	martha.agyiri@gmail.com	Ghana	MSc	KNUST	2014	2016	Food Processing
14.	Safo Kantanka Goodman	M	ogooduman@yahoo.com	Ghana	PhD	KNUST	2013	2016	Poultry Nutrition
15.	Abdul Nurudeen	M	abdulrahmannurudeen@yahoo.com	Ghana	PhD	KNUST	2013	2016	Soil Fertility Management
16.	Raphael Ayizanga	M	raphayi2003@yahoo.com	Ghana	PhD	KNUST	2013	2016	Animal Breeding
17.	Solomon Konlan	M	kspigansoa@yahoo.com	Ghana	PhD	UDS	2013	2016	Ruminant Nutrition
18.	Clarisse Umutoni	F	c.umutoni@cgiar.org	Mali	PhD	CDU	2013	2016	Nat. Resource Governance
19.	Daniel Agbetiameh	M	d.agbetiameh@cgiar.org	Ghana	PhD	KNUST	2013	2016	Aflatoxin Management
20.	Mary Ollenburger	F	M.Ollenburger@wur.nl	Mali	PhD	WUR	2012	2016	Farming Systems

CDU: Cheik Anta Diop University, Dakar, Senegal; KNUST: Kwame Nkrumah University of Science and Technology, Kumasi, Ghana; UDS: University for Development Studies, Tamale, Ghana; UG: University of Ghana, Legon, Accra, Ghana; WUR: Wageningen University, The Netherlands