AGRISERVE

Consultancy for Sustainable Agriculture

Summary Report

Results of the validation of OCP newly developed maize fertilizer formulations for the maize growing belt of Nigeria

Report no 3 of the cooperation agreement between OCP Africa S.A and the International Institute of Tropical Agriculture

Project: Developing efficient and affordable fertilizer products for increased and sustained yields in the maize belt of Nigeria

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Client: OCP Africa

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Acronyms

ADP	Agricultural Development Programme
BUK	Bayero University Kano
CV	Coefficient of Variance
EA	Extension Agent
IAR	Institute of Agricultural Research, Zaria
IITA	International Institute of Tropical Agriculture
LGA	Local Government Area
MSV	Maize Streak Virus
NAERLS	National Agricultural Extension and Research Liaison Services, Zaria
NPK	Nitrogen Phosphate and Potassium containing fertilizer
OCP-Africa	Office Chérefien des Phosphates subsidiary for Africa
ODK	Open Data Kit
SEM	Standard Error of the Mean
SOP	Standard Operating Procedure
VT	Validation Trial

INTRODUCTION:

Fertilizers play a key role in efforts to improve the productivity and herewith the production of maize in Nigeria. Fertilizer use will need to be increased and that requires affordable and efficient fertilizers to be available on the market. The government has tried to address the affordability of the fertilizer in Nigeria, by developing and implementing a subsidy program, and as such stimulate the use of fertilizers. However, that problem will not be resolved without also taking the effectiveness of the fertilizer into account. And, there has been a lot of discussion on the effectiveness of the currently available NPK fertilizers, especially NPK15-15-15. There is a need for more efficient alternative fertilizer formulations that address the prevailing nutrient limitations effectively. OCP-Africa, in collaboration with IITA and AfSIS, has decided to address this problem comprehensively and with a practical approach in mind in which, first, the soils of the maize belt are characterised to get an idea of the prevailing nutrient limitations, and then based on the information develop new fertilizer formulations that would be more effective and provide a better response than the commonly used fertilizer and subsequently testing the new fertilizer formulation at scale.

This report presents the summary of the findings from the validation trials. These trials have been conducted to validate two new fertilizer formulations developed by OCP-Africa on a large number of locations across the maize belt of Nigeria. The new formulations were designed based on the results of a survey of the characteristics of the soils in the maize growing area of Nigeria that covers about two hundred and twenty-five thousand (225,000) square kilometres. Soil samples were collected at approximately 3000 randomly selected locations within the cultivated area and analysed for 15 physical and chemical characteristics. The soil characterisation exercise was conducted in 2016.
The validation trials were conducted in 2017, after careful selection of the locations. The original selection of the 1500 proposed trial site locations was done through random selection from the earlier 3000 locations for the soil survey. For final selection, locations were checked in the field, consent obtained from the farmer to use his/her field and to get commitment for the involvement in managing the trials. Trials were harvested around the period from September to November 2017 and data curation and data analyses was done in 2018.
Implementation of the trials was done with the help of the ADPs, supervised and coordinated by BUK, IAR and NAERLS for the various regions within the maize belt, and IITA Kano station had the overall coordination of the total field campaign and provided technical and logistic support. The project was managed by IITA. Partners were facilitated from the beginning to the end to be able to execute the trials, through training events, planning meetings, provision of means of transport, means of communication and tools for data recording, etc.

METHODS

Site selection

One thousand five hundred (1500) locations were randomly selected from the 3000 locations used for the collection of the soil samples, such that each of the 60 clusters would be represented to ensure proper spread of the trials within the maize belt. The locations were visited in the field in 2016 and early 2017 to identify farmer's fields, get the exact location for the validation trial and get consent of the farmer. 'Consent forms' were uploaded to the ODK server and proposed trial site locations reviewed before final selection was done. The proposed trial site location may deviate from the original location where the soil samples was taken, but it was aimed to keep the distance at a minimum. We identified 1322 locations that were considered suitable for the establishment of the trials. These locations are mapped in Google Maps and can be found here. Further details on the selection of the candidate sites for establishment of the trials is presented in the report on the selection of the trials site locations.

Design and establishment of the trials

Responsibility for the establishment of the trials was given to extension agents (EA) from the local government areas (LGA), who had also been involved in the selection of the locations for the validation trials. These extension agents were referred to as 'facilitators' in the project. We had 51 facilitators involved in the project, with the facilitators organized in teams that are led by a team leader and several teams being supervised by one of the national partners, BUK, IAR, or NAERLS, according the information provided in Table 1.

Table 1 The Local Government Areas serviced by the various teams

Team	State	Local Government Area
IAR TEAMS 1 & 2	Niger	Rafi, Kontagora, Mariga, Katcha, Wushishi, Paikoro, Bosso, Mariga, Lavun, Mashegu
	Kaduna (part)	Birnin Gwari, Kachia, Kauru, Kubau, Kagarko, Kajuru, Sanga, Zango Kataf
NAERLS TEAMS	Nasarawa	Karu, Lafia, Akwanga, Keana, Obi
	Taraba	Ardo Kola, Karim-Lamido, Lau, Yorro
	Plateau	Barkin Ladi, Jos East, Kanam, Langtang North, Langtang South, Mangu, Riyom, Qua'an Pan, Shendam
BUK TEAM 1	Katsina	Kafur, Faskari
	Kaduna	Giwa
BUK TEAM 2	Kaduna	Lere, Igabi, Ikara
	Kano	Rogo, Doguwa
BUK TEAM 3	Bauchi	Toro, Bauchi, Tafawa Balewa, Ningi, Ganjuwa, Alkaleri

The establishment of the trials was monitored using ODK forms. We have been able to establish 872 trials. This is less than what was planned, due to the logistic problems, access to the terrain, security problems, or farmers that withdrew their consent and had already planted, and other.

The validation trials were established on farmers' fields according to a standard protocol and design and managed by the farmer using farmers common practice. The management practices may differ from one trial to the other and from one region to the other. The trials consist of four (4) treatments: a control treatment (no fertilizer application), a treatment with NPK triple 15, a treatment with OCP-F1 fertilizer formu lation and a treatment with OCP-F2 fertilizer formulation. The same application rate is used for the basal fertilizer application: 150 kg/ha, or 3 bags/ha. For all fertilizer treatments, top dressing with urea is done at an application rate of 100 kg/ha. The size of the fertilized plots is 10m by 15m and for the control plot it is 5m by 15m. The unconventional large plot size was chosen to make the result more representative of the farmer's field considering the possible in-field variability resulting from less controlled conditions. The same maize variety was used for all trials, *viz.* IWD-C2-SYN (Sammaz 15), which is an open pollinated, intermediate maturing, white dent/flint, Striga and MSV resistant and drought tolerant variety. The protocol for the validation trials can be found here.

Data collection

Data collection is governed by the standard operating procedure (SOP) established for this purpose and that is implemented in an ODK form for the electronic data recording. That is, data recording is done using smart phones on which *ODK Collect* is installed and on which the forms can be accessed, data can be entered, and filled forms uploaded to the ODK server. We used field books in hardcopy for backup and as fall-back mechanism in case there should be problems with the phones. Supervisors and team leaders were trained on the SOP and the use of the ODK form and were directly overseeing the data recording in the field.

The operating procedure includes taking a sample of 5 plants from the plot for further analysis in the lab. In the lab the following variables are measured: cob weight, moisture content of the grain using a moisture meter, threshing weight and number of kernels. Also, the weight of the stover of the 5 plants is determined. In the field, subsequently, the plants and cobs that are harvested from the 'circular plot' are counted and weighed (that is of stover and cobs). The 'circular plot' measures 10m^2 and allows determining of the plant density, determining plant/cob ratio and other. From the remainder of the plot the cobs are harvested. This is done in batches because the e-scale used measures up to 40 kg maximum. The number of cobs per batch are counted and weighed. For reference a photo is taken of each plot before harvesting with a person holding a pole for measuring height of the plants.

Data from 705 VTs have been uploaded to the ODK server. This was after the 'data management' workshop conducted in February 2018 at BUK in Kano at which we helped team leaders and supervisor to upload data that they had so far not been able to upload. There was data from an additional 70 VTs that had been recorded using the field books only, but that we were not able to enter into the database because of confusion about the identity of the trial, lack of consistency and quality of the data. A number of trials were lost because they were not maintained by the farmer, had been harvested already or were otherwise lost. The location of the 705 VTs that have been harvested can be found here (select the 'OCP VT Harvest 2018' map layer). The locations are also displayed in Plate 1. The spread of the locations of the validation trials is quite good and only few clusters, notably those to the west in Niger state, are not represented.

Plate 1 Map with the location of the 705 Validation Trials for which the data were uploaded to the ODK data server

Data quality control and calculating and evaluating yield response to fertilizer treatment

The data allows for an elaborate quality control and data editing procedure. A number of records are rejected because of missing data, either for the circular plot or for the batches harvested from the plot. Outliers are checked by looking at data values that are outside the range of the mean plus or minus two times the standard deviation for the various variables. This is done on the data sets from the various teams separately and for data from the different treatments separately and for data recorded for the circular plot separately from data recorded for the batches harvested per plot (also data on the cob sample is considered). Outliers are rejected or considered for editing if an obvious typing error is suspected. Subsequently, data is checked for consistency. This is done by calculating and comparing the average cob weight for the few cobs sampled, for the circular plot and for the separate batches harvested from the plot. Finally, the average weight of the sampled cobs as measured in the field is compared to the cobs' weight as measured in the lab for consistency checks. Rather than rejecting the records that failed the consistency checks outright, first it is investigated whether errors can be corrected. Further checks are done on the number of plants and number of cobs harvested (and its ratio) for the circular plot, and for the total number of cobs harvested for the whole plot. This can be evaluated against the expected number of cobs depending on information on the number of rows harvested for the circular plot and the number of rows harvested for the whole plot. Calculations required for the quality control are included in the data sets and edits to the data have been annotated in the data files, allowing for tracking of the changes made. We have worked on the data sets from the various teams separately.

From the resulting data sets the 'yield at harvest' is calculated, which is based on the weight of the cobs as harvested and weighed in the field and converted to kg/ha by applying a conversion factor determined by the size of the harvested area. The 'yield at harvest' is determined for the 'circular plot', with corrections made based on the number of rows harvested (which informs about the correction factor for the effective size of the circular plot). The 'plot' yield at harvest is calculated based on the total weight of the cobs harvested for the plot and corrected for the number of rows harvested that informs about the correction factor to be used for the effective plot size. The 'yield at full plant density' (or 'attainable yield') is calculated by taking the plot yield at harvest and correcting for the number of cobs harvested; that is calculating the yield for an assumed 53,333 cobs harvested per ha. The latter is done because of the large variation in number of cobs harvested for the different plots (or treatments) often observed within one trial and which may compromise the evaluation of the treatment effects. From the data from the circular plot the cob/plant ratio is determined. In general, we find a 0.80 for the cobs per plant ratio for the control treatment, which is lower than the 0.90 we find for the cob per plant ratio for the fertilizer treatments. The 'attainable yield' has not been corrected for the cob/plant ratio.

From the measurements on the cobs in the lab, the mean cob weight for each plot is determined, for comparison with the mean cob weight as measured in the field. Further, the mean and variation in the grain moisture content is determined. The average moisture content was 9.42%, with a standard deviation of 1.40%, which is well below the 12.5% that is used as a standard for dry weight. The yield at harvest can therefore be considered to reflect dry weight. Also, the mean shelling rate was determined. Rather than converting the 'yield at harvest' to grain yield based on the shelling percentage determined for each plot separately, the grain yield is determined by using the same shelling percentage based on the average of the shelling percentage for all observations.

Data are analysed for the various regions as they have been serviced by the different teams under the three national institutions. Results are also presented for each of the states, in which case yield is presented as grain yield. That means that for Kaduna state the data from various teams are combined which will introduce additional variability in the data set. For the other states it will reduce the number of observations, compared to the data sets organised per team/national partner. We used Tukey honestly significant difference (HSD) to determine the levels of significance of the difference in yield between the various treatments for the data organized by state. For the data organized by team/national partner we used the standard error of the mean (SEM) to provide information on the possible significant difference between the yield response for the various treatments.

RESULTS

Yield at harvest for the fertilizer treatments

Figure 1 and Figure 2 present the average 'yield at harvest' for the fertilizer treatments for the various regions serviced by the different teams. Figure 1 presents the results based on data obtained for the whole plot, whereas Figure 2 presents the results based on the data obtained for the 10 m^2 sub-plot, or the circular plot. The error bars represent the standard error of the mean (SEM). The corresponding data is presented in appendix 1, which includes the number of observations (number of trials), the standard deviation, minimum and maximum observed values and the coefficient of variation (CV).
Results for the region supervised by BUK is split in three, corresponding to the mandate areas for the three teams operating under BUK (Katsina-Kaduna, Kano-Kaduna and Bauchi). The number of observations is therefore relatively low compared to the number of observations for the Plateau-Nasarawa-Taraba and the Niger-Kaduna region, and the SEM are relatively high. This applies for both, the data presented in Figure 1 and Figure 2
The trend is consistent for the various regions and for the results obtained for the circular plot, as well as for the whole plot, in that OCP-F2 performs best, followed by OCP-F1 and NPK triple 15. The SEM indicates that these differences are significant, apart for Bauchi.

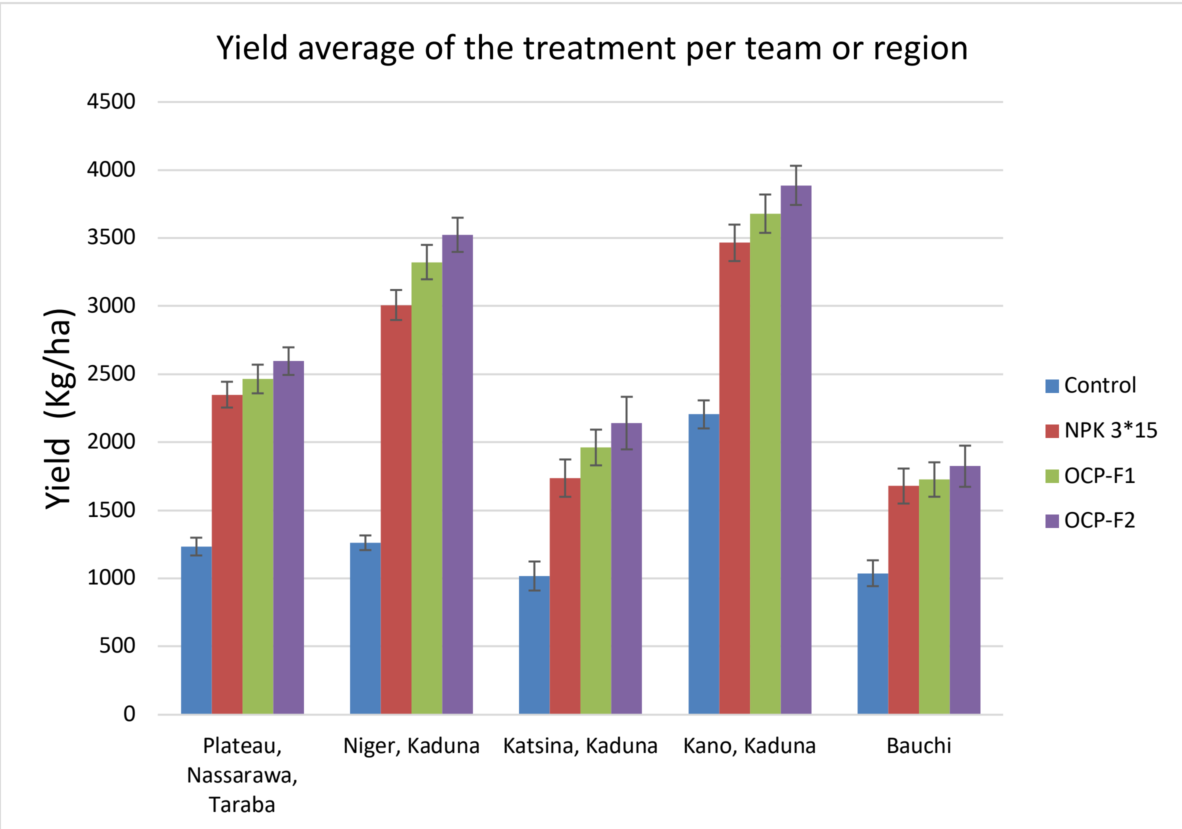


Figure 1 Yield at harvest average for the various treatments based on plot data of the validation trials, differentiated for the various regions and teams. The error bars represent the standard error of the mean (SEM)

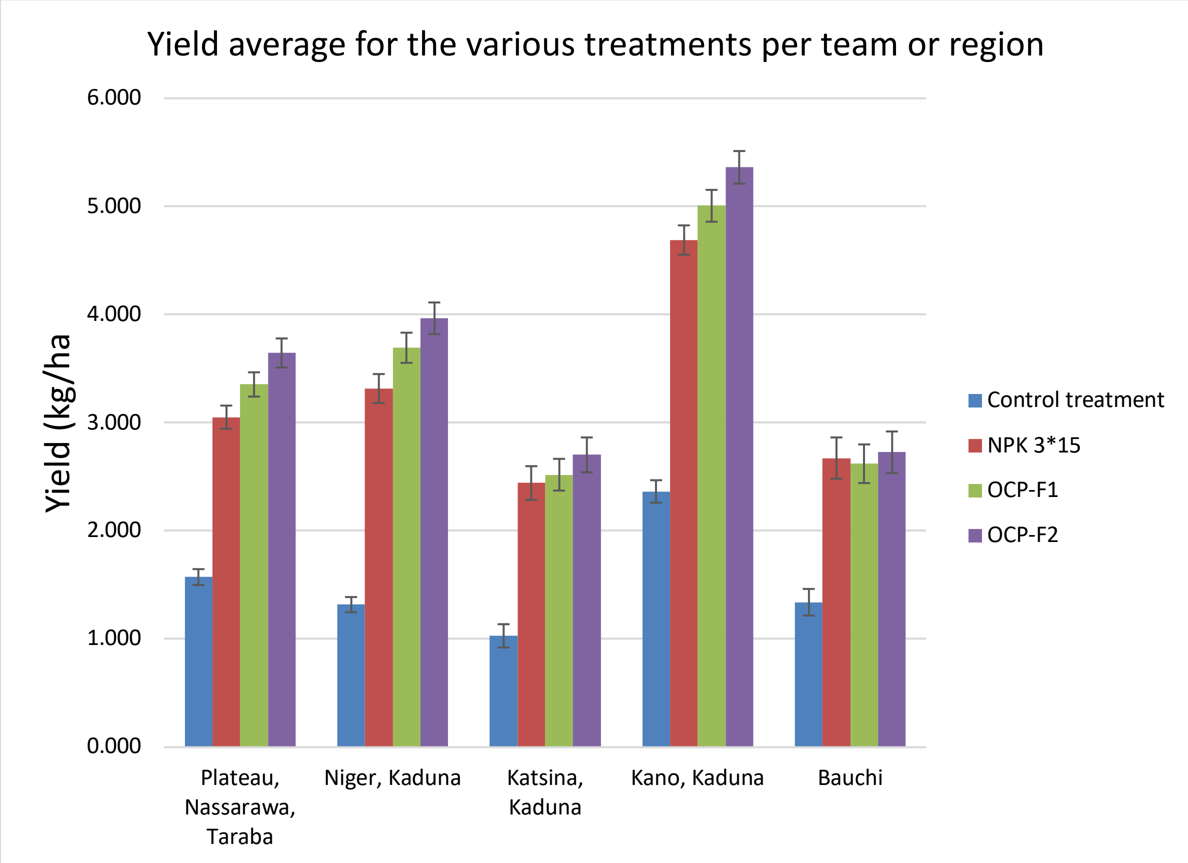


Figure 2 Yield average for the various treatments calculated for the circular plot with results presented for the different regions and teams responsible for the collections of the data. The error bars indicate the Standard Error of the Mean

The ratios of fertilizer treatment yield and control yield range between 1.9 and 2.5 for the NPK triple 15 / control yield ratio and between 2.3 and 3.0 for the OCP-F2 / control yield ratio (excluding Bauchi) for the circular plot data. For the total plot data, the ratios are lower especially for the three teams from BUK (the northern region), which is due to a relative high control yield. This raises some doubts about the reliability of the data from the plot. The results from the circular plot seem to be more credible. For the Bauchi region we find a relatively high number of trials where the crop has failed, and consequently with low yields for all the treatments. It explains the lower yield ratios between the fertilize plots and the control, as well as the relatively high SEM, and the results for the total plot and circular plot are also more consistent.

Attainable levels of 'yield at harvest' or average cob weight

The 'attainable yield level' is obtained by converting the weight of the cobs harvested for the plot to yield per ha based on the number of plants harvested. Based on the plant spacing defined in the protocol we would expect 53,333 plants per ha, but because we only counted the cobs, the 'attainable yield' level represents the yield if 53,333 cobs would have been harvested per ha. This overestimates the yield, as the cob – plant ratio is less than 1. The data obtained from the circular plot indicates that the cob:plant ratio is 0.8 on average for the control treatment and 0.90 on average for the fertilized treatments. The results presented in Figure 3 and table 3 are not corrected for that.

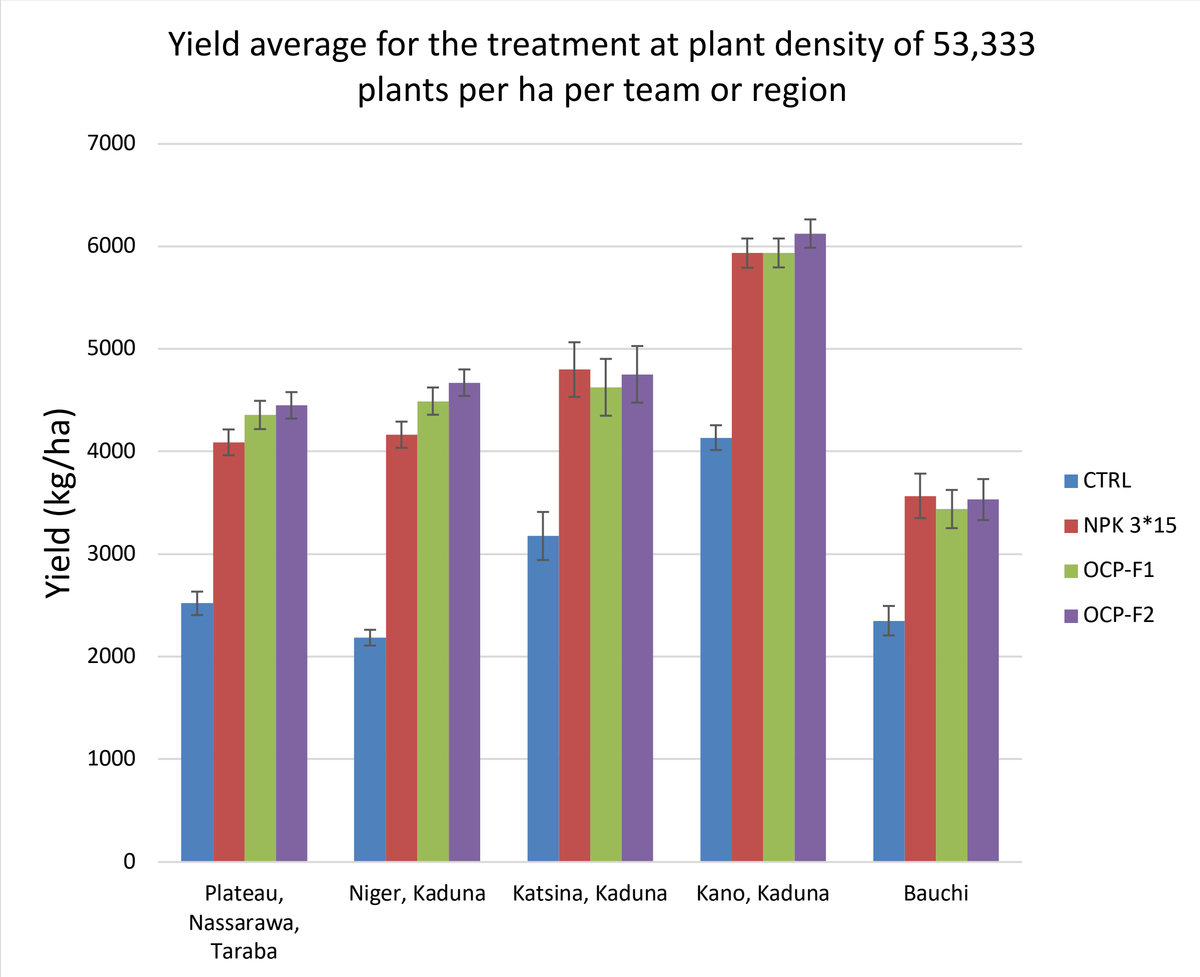


Figure 3 Yield average for the various treatments adjusted to a plant density of 53,333 plants per ha, representing full plant density. Error bars reflect the Standard Error of the Mean

The 'attainable yield' calculated in this way is a true reflection of the average cob weight. Therefore, the results show a significant difference in the average cob weight between treatments for the trials from the Plateau, Nasarawa and Taraba and trials from Niger and Kaduna area. For the data collected from the trials run by the three team from BUK we do not find significant differences.

Yield increase for OCP-F1 and OCP-F2

Figure 4 presents the average yield increase for OCP-F1 and OCP-F2 with respect to NPK triple 15, when taking all observations (trials) into account. In Figure 5 the average yield increase over NPK triple 15 is presented when only taking the best of the two OCP fertilizer formulations for each trial into account. The numbers in the bars indicate the number of observations. So, for the Nasarawa, Plateau and Taraba area we find 63 trials in which OCP-F1 performed better than OCP-F2 and we find 83 trials in which OCP-F2 was the better of the two, for example.

The results presented in Figure 5 represents the situation in case we would be able to select the right formulation for each particular location (when the fertilizer use is properly targeted) and gives a better indication of the average yield increase to be expected.

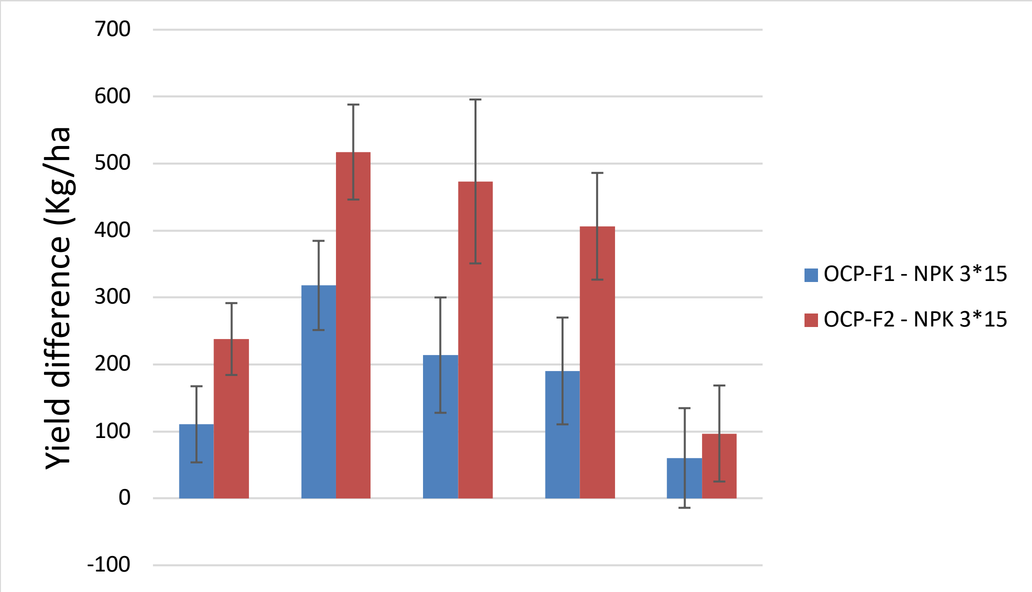


Figure 4 Average difference between OCP-F1 or OCP-F2 fertilizer treatments with the NPK triple 15 fertilizer treatment. Error bars indicate standard error of the mean

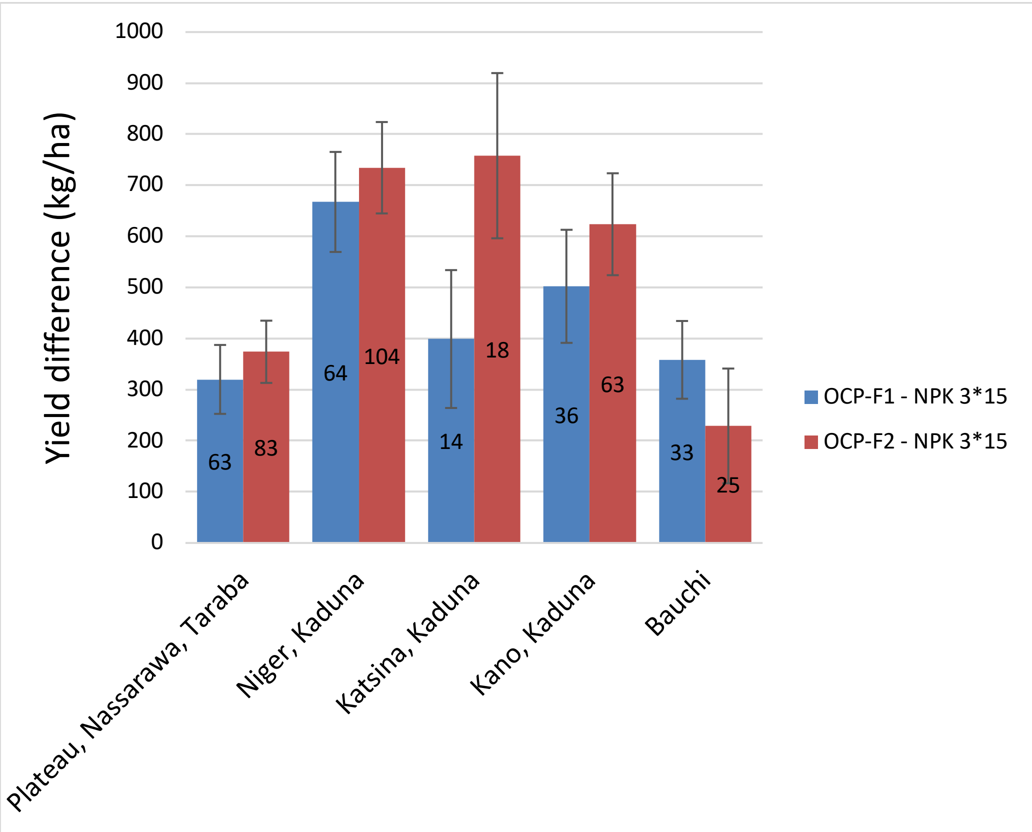


Figure 5 Average yield increase for either OCP-F1 or OCP-F2 treatment with respect to the NPK triple 15 treatment for the various regions of the maize belt in Nigeria for cases in which OCP-F1 is the best performing OCP fertilizer and cases in which OCP-F2 is the best performing OCP fertilizer. Error bars represent standard error of the mean numbers indicate the number of observations for which these conditions apply.

When considering the average yield increase for all observations we see that OCP-F2 performs significantly better than OCP-F1 (apart from Bauchi where this is not significant). The average yield increase for OCP-F2 for the Niger/Kaduna, Katsina/Kaduna, Kano/Kaduna area of observations ranges from 400 kg/ha to 520 kg/ha approximately, and these are in themselves not significantly different. The average yield increase for OCP-F2 for the Plateau, Nasarawa and Taraba, is 238 kg/ha and for the Bauchi area of observation it is 97 kg/ha. There does not seem to be a direct relationship between the yield level and the expected yield increase over NPK triple 15, which suggest that these effects are region specific. The trend for OCP-F1 is the same for OCP-F2

We find contrasting results for the performance of the OCP-F1 and OCP-F2 fertilizers. For example, for the Niger-Kaduna 'area of observation' we find a difference of 565 kg/ha on average between the yield obtained with OCP-F1 and OCP-F2 fertilizer for any particular trial. Therefore, it is justified to treat the results for these two cases separately. We see, when taking the better of the two OCP fertilizer, the average yield increases considerably and the difference between OCP-F! and OCP-F2 is considerably less, though varying between one region and the other (Figure 5).
Average yield increase for OCP-F2 ranges from 624 kg/ha for the Kano 'area of observation' to 758 kg/ha for the Katsina-Kaduna 'area of observation', and that the differences between the Niger-Kaduna, Katsina-Kaduna and Kano-Kaduna are not significant. The yield increase for OCP-F2 for Plateau, Nasarawa & Taraba 'area of observation' has improved to 374 kg/ha and for the Bauchi-Kaduna 'area of observation' the yield increase is 229 kg/ha.

When selecting only the trials where OCP-F1 performs better than OCP-F2, the average yield increase for OCP-F1 compared to NPK triple 15 ranges from 320 kg/ha for the Plateau, Nasarawa and Taraba 'area of observation' to 667 kg/ha on average for the Niger-Kaduna area of observation. The differences between Plateau-Nasarawa-Taraba and Bauchi on the one hand and Niger-Kaduna on the other hand are significant. Note that Bauchi is no longer the least performing in this case and the pattern is different from what is observed in Figure 4. The strongest improvement in yield increase is observed for those regions where the overall yield increase (when measured as average over all observations) is lowest and that is for the Plateau-Nasarawa-Taraba and Bauchi regions.

In terms of percentage the average yield increase of OCP-F1 over NPK triple 15, treating all the trials without discrimination, ranges from a 4% yield increase for Bauchi to a 12% yield increase on average for the Katsina 'area of observation'. And it ranges from 6% for Bauchi to 27% for the Katsina-Kaduna 'area of observation' for the OCP-F2 treatment.

When discriminating between trials in terms of the best OCP fertilizer, the average percentage increase in yield compared to NPK triple 15 ranges from 14% for Bauchi to 44% for the Katsina-Kaduna 'area of observation' for OCP-F2 and from 14% to 23% yield increase in the case of OCP-F1 also for Bauchi and the Katsina-Kaduna 'areas of observation' respectively. The percent yield increase is summarized in Table 2. It seems that for all regions investment in production and use of these alternative fertilizers is justified, if it is possible to target fertilizer use.

Table 2 Percent yield increase for OCP-F1 and OCP-F2 compared to NPK triple 15 as average of the total number of observations and as average of those observations where either OCP-F1 or OCP-F2 is the best performing OCP fertilizer

Regions serviced by the various teams	OCP-F1 overall (%)	OCP-F2 overall (%)	OCP-F1 targeted (%)	OCP-F2 targeted (%)
Plateau, Nasarawa, Taraba	5	10	14	16
Niger, (Kaduna)	11	17	22	24
Katsina, (Kaduna)	12	27	23	44
Kano, (Kaduna)	5	12	14	18
Bauchi	4	6	21	14

Grain Yield response to fertilizer treatment by state

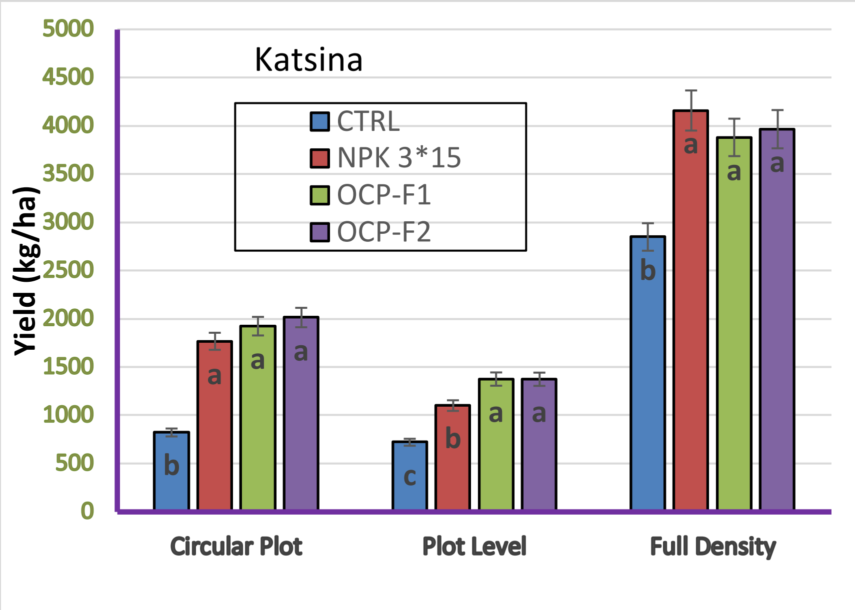
In the graphs below the grain yield response to the fertilizer treatment is presented for each state separately. Grain yield is obtained by taking 80% of the ‘yield at harvest’. The 80% is the average of the shelling rate that we determined for each cob sampled from the field. We find very little variation and therefore we are justified to apply the same shelling percentage to the average yield at harvest for each of the states. In each graph the ‘circular plot’ yield, the ‘plot’ yield and the attainable yield level is presented. The letters in the bar indicate mean separation. The same letter indicates yield similarity at 5% statistical level of significance using Tukey HSD.

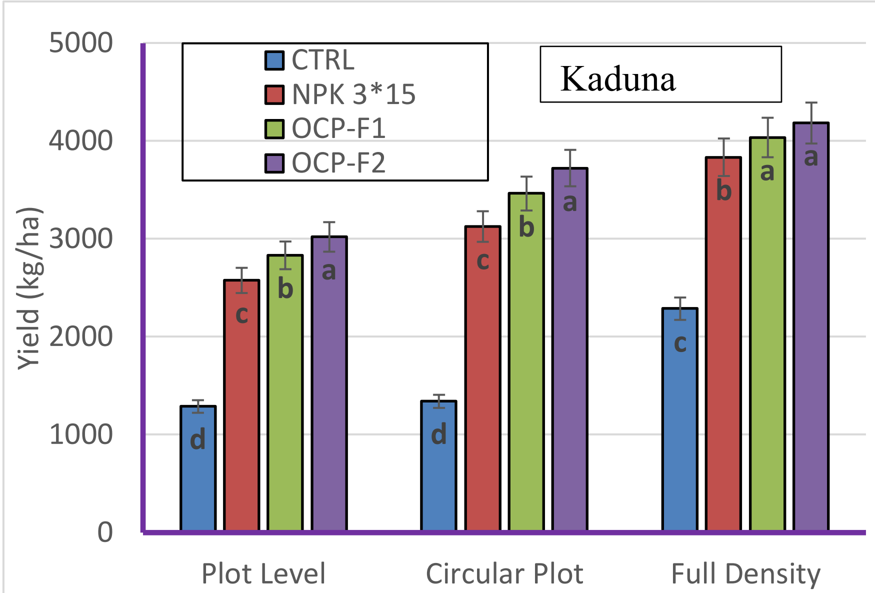
Based on the evidence from Kaduna, Niger, Plateau, Nasarawa and Taraba we conclude that there are significant differences in the grain yield obtained for each of the treatments (each fertilizer treatment and the control). We see that the evidence based on the plot level data is less strong, but that is because of the plot level data is less accurate compared to the yield prediction based on circular plot data.

From the yield prediction at full plant density we see that average cob yield (average grain yield per cob) is significantly higher for the fertilizer treatments compared to the control, and for the OCP fertilizers compared to the NPK triple 15. There is no evidence that there is a significant difference in average cob grain weight between both OCP fertilizers. These results indicate that the yield increase is for a large part due to increased average cob weight.

Attainable yield levels for the fertilizer trials, with this application rate (150 kg/ha of basal application and 100 kg/ha top dressing with urea) ranges from around 3 t/ha for Niger and Plateau state to around 4 t/ha for Kaduna, Katsina and Taraba state to 5 t/ha for the Kano state area.

Figure 6 (next pages) Grain yield average for the various fertilizer treatments using different prediction approaches for the individual states in the maize belt of Nigeria. Letters in the bars indicates mean separation. Same letter for different bars indicates yield similarity at 5% statistical level of significance using Tukey HSD


Katsina
CTRL
NPK 3*15
OCP-F1
OCP-F2
Yield (kg/ha)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Circular Plot
Plot Level
Full Density


Kaduna
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OCP-F1
OCP-F2
Yield (kg/ha)
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4000
3000
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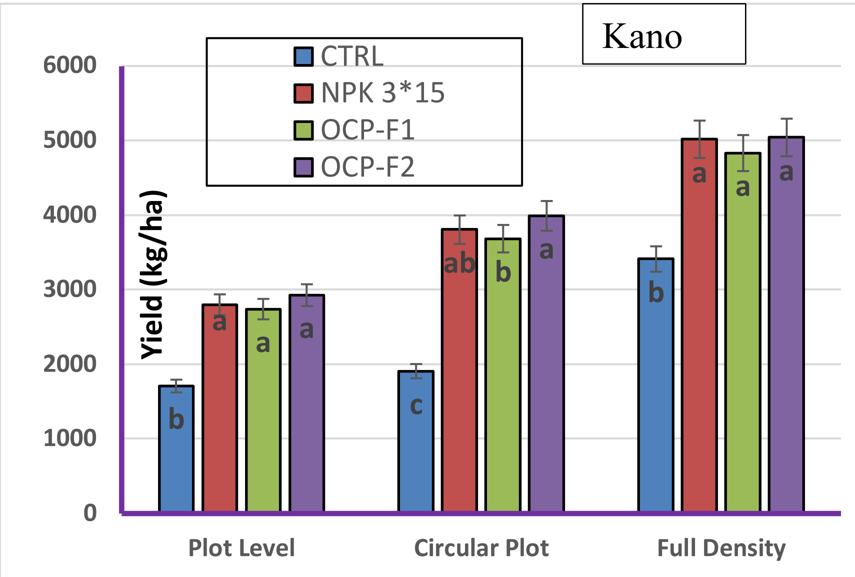
Full Density


Kano
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NPK 3*15
OCP-F1
OCP-F2
Yield (kg/ha)
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5000
4000
3000
2000
1000
0
Plot Level
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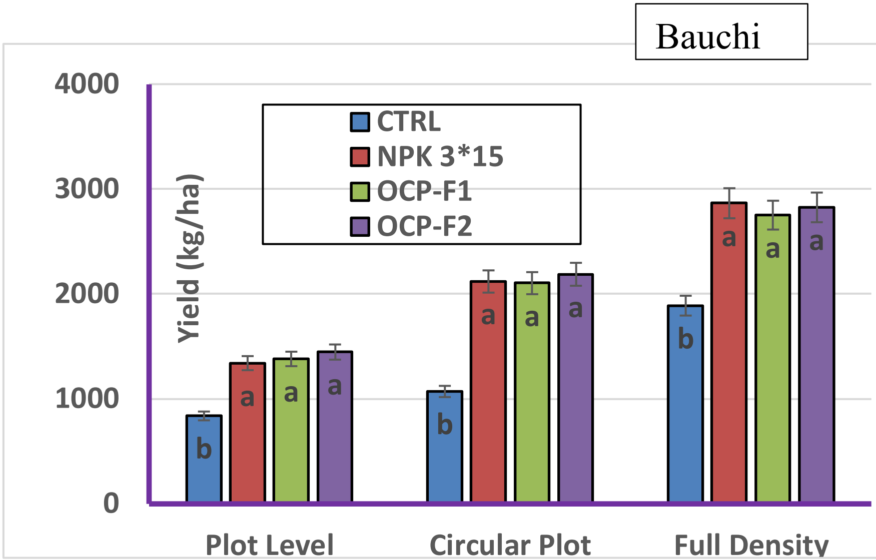
Full Density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OCP-F2
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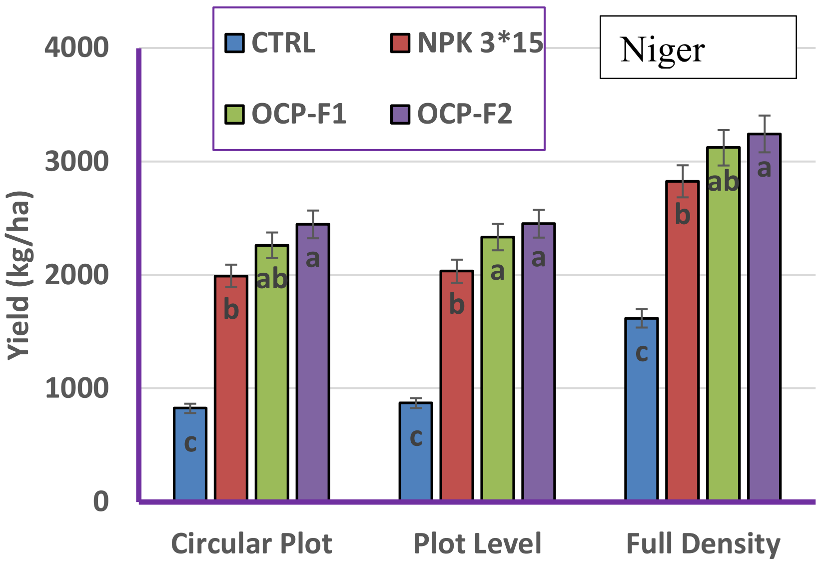
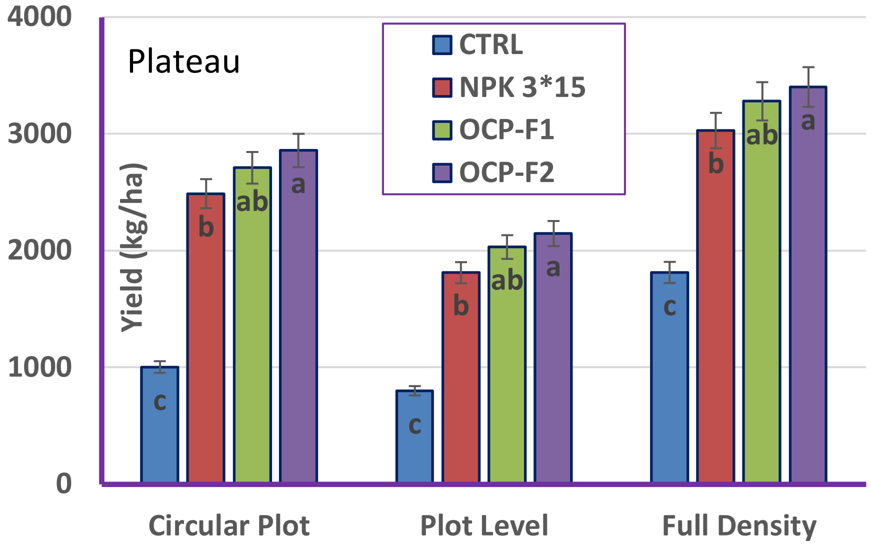
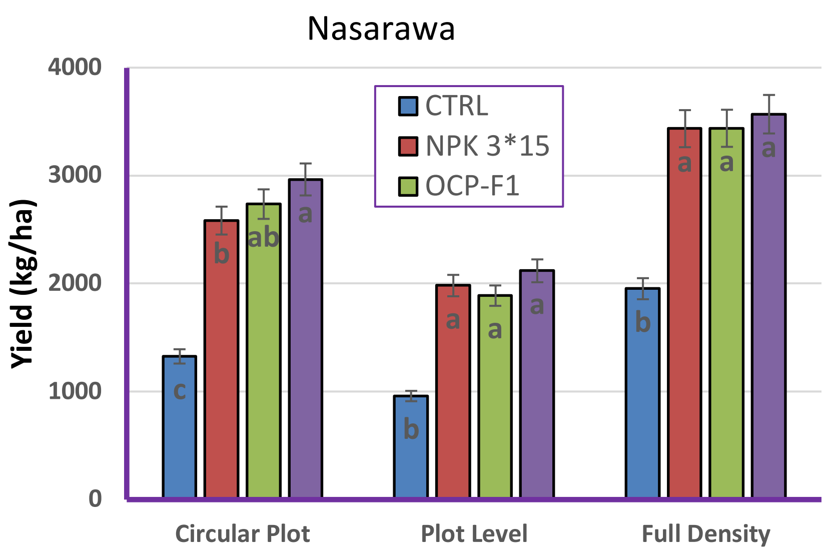
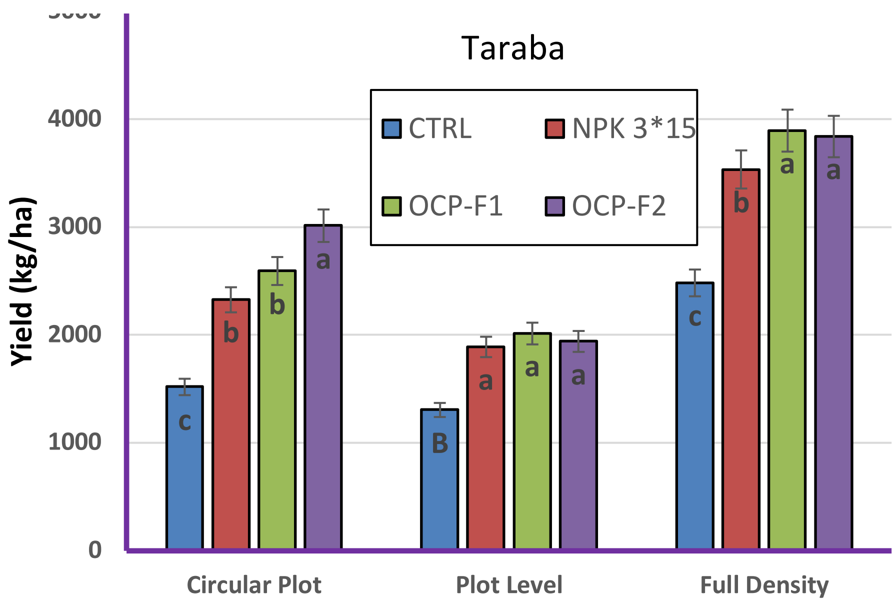
Circular Plot
Full Density


Niger
CTRL
NPK 3*15
OCP-F1
OCP-F2
Yield (kg/ha)
4000
3000
2000
1000
0
c b ab a
c b a a
c b ab a
Circular Plot
Plot Level
Full Density


Plateau
CTRL
NPK 3*15
OCP-F1
OCP-F2
Yield (kg/ha)
4000
3000
2000
1000
0
c b ab a
c b ab a
c b ab a
Circular Plot
Plot Level
Full Density


Nasarawa
CTRL
NPK 3*15
OCP-F1
Yield (kg/ha)
4000
3000
2000
1000
0
c b ab a
b a a a
b a a a
Circular Plot
Plot Level
Full Density


Taraba
CTRL
NPK 3*15
OCP-F1
OCP-F2
Yield (kg/ha)
4000
3000
2000
1000
0
c b b a
B a a a
c b a a
Circular Plot
Plot Level
Full Density

Discussion

The contrasting results for the performance of the OCP-F1 and OCP-F2 fertilizers indicates that the OCP fertilizers perform different under the same conditions, or, perform best under different conditions. The two OCP fertilizers should be evaluated separately and the results shows that both fertilizers perform better than NPK triple 15, ranging from 14% to 25% on average (for one region we found 44% increase for OCP-F2), if these fertilizers are applied for those conditions that they are best suited for.

We observe the trends for the yield increase are the same for OCP-F1 and OCP-F2 across the various regions or states. We also observe that the yield increase for OCP-F1 and OCP-F2 is not correlated directly with the general yield level (the higher yield in general does not does not show also higher and larger differences in yield obtained with OCP fertilizers compared to NPK triple 15), which indicates that there are different factors that determine the general yield response to fertilizer application, from the factors that determine the response to either OCP-F1 and OCP-F2 and that relate to the soil condition. These factors vary within the region or state, rather than between region or states. We do not know at which scale these relevant factors vary, but the data suggest this variation is quite local.

The yield varies from region to region and this may be due to the different ecologies and weather conditions, as well as to the general management conditions (e.g. different time of planting by the different teams). It is important to realize there is also a large variability between the individual trials. This is evidenced by the general high coefficient of variation (CV) presented in Appendix 1, Table 3. These are consistently high for the circular plot and whole plot observations, ranging from 0.40 to 0.78. BUK team 2 (Kano region) has relative low CV scores indicating that the trials are well executed, while the Bauchi team shows relative high CV values, which is related to the relatively high percentage of trials where the crop seems to have failed with yields well below the 1 t/ha and number of cobs harvested very much lower than what is expected. This is likely related to management of the trials, because attainable yield levels are similar to those of Niger and Plateau state.

We see large differences between the attainable yield and the actual yield obtained for the plot, which is explained by the generally low number of plants harvested from the plot. This is rather extreme for Bauchi and Katsina areas with for Katsina 30 to 35% of the expected plants harvested on average per plot. This is confirmed by the low plant count at harvest for the circular plot. However, also for other states the number of plants lost is surprisingly high, e.g. for Plateau, Nasarawa and Taraba state the number of cobs harvested is around 60% of what would be expected at full plant density. We have to assume this is related to the management of the trials. With these low numbers of plants/cobs harvested and crop failure we have an explanation for why we do not find any significant difference in the response to the various fertilizer treatments and herewith confirms the conclusion that we may expect a clear difference in the response to the OCP-fertilizer application under normal conditions. The question remains whether the results of the trials are representative of what happens on farmer's fields. The data for these states should not be used for any further economic evaluation of the fertilizer use.

We also may find differences in the plant density at harvest between control and fertilized plots. For example, for BUK team 3 (Bauchi), the cobs harvested for the 'control' plots is on average 56% of full plant density, while that for the fertilizer treatments is around 45%. For Taraba, Nasarawa and Plateau the plant density at harvest is 75% for the control, compared to the 60% for the fertilized plots. This means that the average yield for the 'control' treatment is overestimated compared to the fertilizer treatments and that the difference between control yield and yield of the fertilizer is larger that indicated by the result of these trials, unless there is an reasonable explanation why plant density for the fertilizer treatments is less. This needs to be taken into account when cost-benefit calculation on fertilizer use is conducted based on this data.

For the 'attainable yield' levels this difference in plant density at harvest between the treatments is not relevant. However, also in this case we overestimate the 'control' yield. The cob/plant ratio for the 'control' treatment was found to be 0.8 on average, whereas this is 0.9 for the fertilized plots and this is not corrected for in the way the 'attainable' yield is calculated.

The yield data shows a very large random variability, and this applies to the response to fertilizer treatment as well as to the 'control yield'. Comparing response of OCP-F1 and OCP-F2 to NPK triple 15 often results in negative values therefore. Minimum and maximum values for the various regions are indicated in Table 3. The probability of getting a negative response for OCP-F2, compared to NPK triple 15, for the Niger and Kaduna area of observation is still one out of four (25%), for example. For OCP-F1, the probability of getting a negative response compared to NPK triple 15 is even 36.3%. These percentages may probably be reduced when applying good agricultural practices but will also require proper targeting of the fertilizer to the soil and environment conditions for which it is best suited. This will automatically also increase the level of the yield response. Nevertheless, farmers will consider the risk of investing in a new fertilizer and the probability of getting a negative response will need to be considered in the price setting for the new fertilizer.

Appendix 1 Data table with the results of the statistical analysis underlying the various graphs presented in this report

Table 3 Descriptive statistics of the yield data for the fertilizer treatments for the different data set provided by the various teams for the different areas of observation.

NAERLS	AVR	N	STD EV	SE	MAX	MIN	CV
Average control yield cplot	1.573	157	0.921	0.073	4.864	0.130	0.59
Average yield Triple 15 cplot	3.052	166	1.375	0.107	7.610	1.043	0.45
Average yield OCP Formula 1 cplot	3.354	168	1.457	0.112	8.032	0.320	0.43
Average yield OCP F2 cplot	3.645	167	1.734	0.134	8.990	0.542	0.48
Average control yield	1235	151	803	65	4900	67	0.65
Average yield NPK triple 15	2351	155	1180	95	5591	438	0.50
Average yield OCP F1	2466	151	1294	105	6006	546	0.52
Average yield OCPF2	2597	156	1267	101	5923	344	0.49
Average yield control corrected for plant density	2521	144	1372	114	8134	286	0.54
Average yield NPK triple 15 at full PD	4091	156	1570	126	10723	1186	0.38
Average yield OCP F1 at full PD	4358	155	1717	138	11169	1089	0.39
Average yield OCP F2 at full PD	4451	155	1608	129	11298	862	0.36
Average difference yield OCP F1 - NPK triple 15	111	142	678	57	3103	-2165	
Average difference yield OCP F2 - NPK triple 15	238	148	653	54	3296	-1277	
Average diff yield OCP-F1 - NPK 3*15 (F1>F2)	320	63	536	67	2182	-918	
Average difference yield OCP-F2 - NPK 3*15 (F2 > F1)	374	83	555	61	1750	-981	
IAR							
Yield at harvest Cplot_CNTR trt average	1.318	174	0.928	0.070	6.830	0.115	0.70
Yield at harvest Cplot_NPK-15-15-15	3.316	175	1.769	0.134	9.045	0.369	0.53
Yield at harvest Cplot OCP-F1	3.693	174	1.842	0.140	9.445	0.550	0.50

Yield at harvest Cplot_OCP-F2	3.966	174	1.931	0.146	10.004	0.705	0.49
Stats for plot yield at harvest							
Yield at harvest CNTRL_avr	1263	165	693	54	4034	166	0.55
Yield at harvest NPK triple 15_avr	3009	172	1447	110	7440	394	0.48
Yield at harvest OCP-F1_avr	3324	172	1657	126	8111	387	0.50
Yield at harvest OCP-F2_avr	3524	172	1648	126	8862	494	0.47
Yield at harvest corr for PD_CNTR	2187	158	965	77	5116	589	0.44
Yield at harvest corr for PD_NPK 3*15	4165	170	1663	128	9949	1304	0.40
Yield at harvest corr for PD_OCP-F1	4493	171	1738	133	10261	1343	0.39
Yield a harvest corr for PD_OCP-F2	4672	171	1695	130	10336	1253	0.36
Yield diff OCP-F1 NPK trip15_average	318	168	864	67	2911	-1790	
Yield diff OCP-F2 – NPK trip15_average	517	168	920	71	3464	-1365	
Yield diff OCP-F1 – NPK 3*15 (IF F1>F2)	667	64	784	98	2621	-744	
Yield diff OCP-F1 – NPK 3*15 (IF F2>F1)	734	104	912	89	3464	-1365	
BUK team 1							
Yield_at_harvest_cplot_NPK triple15	2.443	59	1.197	0.156	5.809	0.308	0.49
Yield_at_harvest_cplot_CTRL	1.030	54	0.791	0.108	3.292	0.200	0.77
Yield_harvest_cplot_OCP-F1	2.519	57	1.109	0.147	5.756	0.647	0.44
Yield_harvest_cplot_OCP-F2	2.703	57	1.217	0.161	5.147	0.372	0.45
Yield_harvest_plot NPK 3*15	1738	40	868	137	3887	86	0.50
Yield_harvest_plot CTRL	1019	30	584	107	2631	326	0.57
Yield_harvest_plot OCP-F1	1963	35	776	131	3226	447	0.40
Yield_harvest_plot OCP-F2	2142	36	1159	193	5366	228	0.54
Yield_harvest_NPK 3-15_corr PD	4800	39	1664	267	9843	1907	0.35
Yield_harvest_corr PD_CTRL	3178	29	1263	234	6343	1141	0.40
Yield_harvest_corr PD_OCP-F1	4627	34	1616	277	9184	2302	0.35
Yeld_harvest_corr PD_OCP-F2	4754	34	1610	276	8698	1766	0.34

Yield_diff_OCP-F1–NPK 3-15	214	34	502	86	1371	-874	
Yield_diff_OCP-F2–NPK 3-15	473	35	724	122	2607	-1110	
Yield diff_F1–NPK3-15 (F1>F2)	399	14	505	135	1371	-378	
Yield diff_F1–NPK3-15 (F2>F1)	758	18	686	162	2607	-214	
BUK team 2							
C-plot data							
Average yield ctrl	2.365	104	1.060	0.104	5.807	0.523	0.45
Avr yield NPK 3*15	4.689	105	1.393	0.136	7.770	1.710	0.30
Avr yield OCP F1	5.006	106	1.515	0.147	8.393	1.148	0.30
Avr yield OCP F2	5.361	106	1.554	0.151	9.240	1.795	0.29
Plot data							
Avr Yield at Harvest_CTRL plot	2206	102	1040	103	4882	428	0.47
Avr Yield at Harvest_NPK 3*15	3465	104	1367	134	6811	731	0.39
Avr Yield at Harvest OCP-F1	3680	105	1444	141	7742	611	0.39
Avr Yield at Harvest OCP-F2	3888	106	1482	144	7599	806	0.38
Plot data at full PD							
Avr Yield CTRL plot at full PD	4137	102	1222	121	6650	1152	0.30
Avr Yield NPK triple 15 at full PD	5935	104	1456	143	9109	2215	0.25
Avr Yield OCP-F1 at full PD	5937	104	1436	141	11049	2244	0.24
Avr Yield OCP-F2 at full PD	6126	105	1415	138	11996	2055	0.23
Avr yield diff OCP-F1–NPK 3-15	191	100	798	80	1985	-2077	
Avr yield diff OCP-F2–NPK 3-15	407	101	801	80	2800	-1268	
Avr yield diff OCP-F1 - triple 15 (F1>F2)	502	36	664	111	1985	-418	
Avr yield diff OCP-F1 - triple 15 (F2>F1)	624	63	792	100	2800	-891	
BUK team 3							
C-Plot data							
Average yield ctrl	1.341	72	1.043	0.123	4.975	0.180	0.78
Avr yield NPK 3*15	2.673	74	1.646	0.191	7.975	0.273	0.62
Avr yield OCP F1	2.621	73	1.527	0.179	7.196	0.290	0.58
Avr yield OCP F2	2.727	71	1.623	0.193	6.780	0.355	0.60
Plot data							
Avr Yield at Harvest_CTRL plot	1039	63	754	95	3733	110	0.73

Avr Yield at Harvest_NPK 3*15	1679	64	1029	129	4983	135	0.61
Avr Yield at Harvest OCP-F1	1727	62	996	127	4278	204	0.58
Avr Yield at Harvest OCP-F2	1825	61	1181	151	5641	269	0.65
Yield data corrected for plant density							
Avr Yield CTRL plot at full PD	2352	67	1177	144	5886	615	0.50
Avr Yield NPK triple 15 at full PD	3569	70	1814	217	9533	1051	0.51
Avr Yield OCP-F1 at full PD	3441	70	1560	186	8945	657	0.45
Avr Yield OCP-F2 at full PD	3533	69	1661	200	7638	683	0.47
Avr yield diff OCP-F1 – NPK 3-15	61	59	572	74	1218	-1902	
Avr yield diff OCP-F2 – NPK 3-15	97	57	542	72	1711	-1272	
Avr yield diff OCP-F1 - triple 15 (F1>F2)	358	33	437	76	1218	-440	
Avr yield diff OCP-F1 - triple 15 (F2>F1)	229	25	562	112	1711	-736	

Appendix 2 Data table with the average grain yield response to fertilizer treatments per state using different approaches for estimating grain yield

Table 4 Grain yield response to fertilizer treatments using the circular plot-based data and plot-based data and for simulated full plant density, arranged by State

	Treatment			
Katsina	CTRL (kg/ha)	NPK 3*15 (kg/ha)	OCP-F1 (kg/ha)	OCP-F2 (kg/ha)
Circular Plot	823	1768	1924	2014
Plot Level	722	1102	1376	1374
Full Density	2848	4159	3880	3965
Nasarawa				
Circular Plot	1326	2584	2736	2965
Plot Level	959	1982	1889	2119
Full Density	1953	3435	3438	3569
Niger				
Circular Plot	825	1992	2262	2446
Plot Level	871	2034	2335	2452
Full Density	1618	2826	3121	3243
Plateau				
Circular Plot	1004	2488	2710	2858
Plot Level	801	1812	2032	2147
Full Density	1814	3029	3279	3401
Taraba				
Circular Plot	1518	2326	2592	3012
Plot Level	1305	1889	2013	1940
Full Density	2482	3533	3893	3838
Kano				
Plot Level	1709	2799	2741	2928
Circular Plot	1909	3806	3685	3991
Full Density	3412	5018	4833	5042
Kaduna				
Plot Level	1288	2575	2831	3019
Circular Plot	1340	3125	3462	3722
Full Density	2286	3833	4035	4182
Bauchi				
Plot Level	838	1341	1381	1447
Circular Plot	1071	2119	2103	2188
Full Density	1889	2865	2752	2825