Synergizing fertilizer micro-dosing and indigenous vegetable production to enhance food and economic security of West African farmers
(CIFSRF Phase 2)

Project Number 107983

Location of Study: Nigeria and Benin Republic

Final report of agronomic trial and Water management of fertilizer micro-dosing technology on traditional leafy vegetables

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Content

Key Messages

- The average fresh leaf yields of the four vegetables increased from 1.3 and 3.2 kg/m² under control (no fertilizer) reaching a maximum of 2.55 and 6.5 kg/m² under 60 kg/ha of urea-N application in Benin and Nigeria, respectively. A contributory factor to this yield increase is the basal application of organic manure at a minimum rate of 5 t ha^{-1} to sustain the soil productivity.

- The total variable cost incurred on each $6m^2$ plot at 0 kg, 20 kg, 40 kg, 60 kg and 80 kg Urea-N/ha were $2.94, $3.32, $3.34, $3.37 and $3.42 while the total incomes were $23.65, $40.51, $45.89, $61.08 and $39.52, respectively**.**

- Partial nutrient balance computation (nutrient input minus vegetable leaves nutrient uptake) showed that continuous vegetable (*Solanum*, *Telfaria*, *Amaranths* and African basil) production without manure depleted the soil in N (-268.3 to -30.8 to kg/ha for D40, -195.0 to -4.5 kg/ha for D60), P(-65.0 to -18.3 for D40 and –286.0 to -18.7 kg/ha for D60) and K (-336.3 to -2.3 to kg/ha for D40, -2703.2 to -2.4 kg/ha for D60), although soil nutrient mining was moderate with African Basil.

- The combined application of fertilizer micro-dosing and manure (5t/ha) in continuous production during one year of *Amaranth* (4 cycles), *Telfairia* (one cycle), *Solanum* (2 cycles) and African Basil (2 cycles) led to a positive N balance under *Amaranth* (+60.8 kg/ha for D60) and African Basil (7.4 and 33.8 kg/ha for D40 and D60 respectively). K and P mining is corrected only when manure (5t.ha) is renewed at each crop cycle or higher amount is applied instead.

- When fertilizer microdosing is combined with 5 tons of organic manure, our results showed that the residual macronutrients in the soils after three cycles of vegetable harvest was not significantly from the traditional fertilizer applications method. This shows that fertilizer micro-dosing can be used to sustainably produce these vegetables when combined with organic manure at the rate of 5 t per ha.

- Using polynomial regression, an optimum urea fertilizer micro-dose rate of 40 kg urea-N rate was established for the three vegetables during two cycles of planting in Nigeria, while only *Amaranthus* had the highest yield at 40 kg urea-N in Benin and it was 60 kg/ha for *Solanum macrocarpon* and *Ocimum gratissimum*.

- Results of soil analyses showed that the soils of both the forest and savanna ecosystems were able to sustain high vegetable yield under fertilizer micro-dose rate at 40 kg/ha over the three years of study when compared with the farmers recommended rates.

- The average water use by the vegetables in each crop cycle (dry season and rainy season)ranged from 285-377 mm in the forest and savanna agro-ecologies, respectively. Fresh biomass yield increased at an average rate of 31 kg ha^{-1} per 1 mm of water used in the rainforest, while in the dry savanna while it increased at an average rate of 27 kg ha^{-1}).

- The water required to produce a Kg of Amaranth was reduced from 450 L on the traditional irrigation method to 200 L under the capillary irrigation. This translated to water saving of approximately 2.2 million L/ha in forest to an approximate 8 million L/ha in the savanna ecosystem.

1 SUMMARY OF RESULTS

We tested urea microdosing on three traditional leafy vegetables in each county Benin and Nigeria: *Amaranthus sp* (Tete abalaye, Fotete), *Solanum macrocarpum* (Gboma, Igbagba) in both countries, *Telferia occidentalis (*Ugu) in Nigeria, and *Ocimum gratissimum* (Tchiayo) in Benin. The test combined urea at five levels (0, 20; 40; 60 and 80 kg/ha of urea-N) with basal manure (at 5t/ha except form the 80 kg/ha urea level), applied at two dates (10 and 20 days after transplanting. The Amaranthus at both the Nigerian rainforest and savanna locations (2.5-4.0 kg fresh leaves /m²) significantly out-yielded the Amaranthus planted in Benin Republic (maximum of 1.6 kg/m²). This is explained by the wide difference between the seeding population used in Nigeria (550 plants/bed) and Benin Republic (184 plants/bed) and probably by the landraces. For *igbagba (Solanum macrocarpon)*, the leaf yield in Nigeria is 3.2-8.3 kg/m² across the urea-N rates while in Benin the leaf yield is 3.26 kg/m². For the two countries and the three agro-ecological zones (rainforest, dry and humid savanna), an optimum of 40-60 kg urea-N rate was established for the three vegetables during two cycles of planting (dry and wet season) in a year. We found that timing of application (transplantation time or 10 days after T) had no significant influence on leaf yield. Vegetables that received N application were significantly greener than the control vegetables across locations and seasons with no significant differences amongst the vegetables grown on urea-N-treated soils. It is also noted that the vegetables grown in the savanna were greener than in the forest zones in Nigeria. The P contents of the vegetables did not respond to the different rates of urea-N application. The Fe content of *Igbagba* was significantly higher compared to *Tete* but did not significantly vary with rates of applied urea-N. The Zn contents in plant tissues however did not differ significantly between *Igbagba* and *Tete* and also did not respond to rates of urea-N treatment. Fresh biomass of *Amaranthus* and *Solanum* increased at an average rate of 27 kg ha^{-1} and 36 kg ha^{-1} respectively and by 32 kg ha^{1} and 48 kg ha^{-1} per mL of water used respectively in the humid savanna of Nigeria. We compared a capillary irrigation innovation with the traditional sprinkler irrigation system. The capillary irrigation innovation saved an average of 1.2 and 7.4 million L of water per ha per each growing season of 3 months respectively during the wet and dry seasons in Nigeria.

2 Research Objectives

The agronomy trials were carried out with the main objective of fine tuning the fertilizer microdosing technology of InuWaM on indigenous vegetables using the NiCanVeg Technology for their cultivation. Fertilizer microdosing was successfully used on sorghum in Benin and Burkina Faso. It has however not been reported for indigenous vegetables. This trial was designed to test the effects of fertilizer microdosing at different rates and time intervals of application on the yield and quality of Ugu (*Telfairia occidentalis, Nigeria only*), Tete abalaye (*Amaranthus viridis*), Igbagba (*Solanum macrocarpon*) and *Ocimum gratissimum* (Tchiayo, Benin only).

3 Materials and methods

3.1 Experimental sites and experimental design:

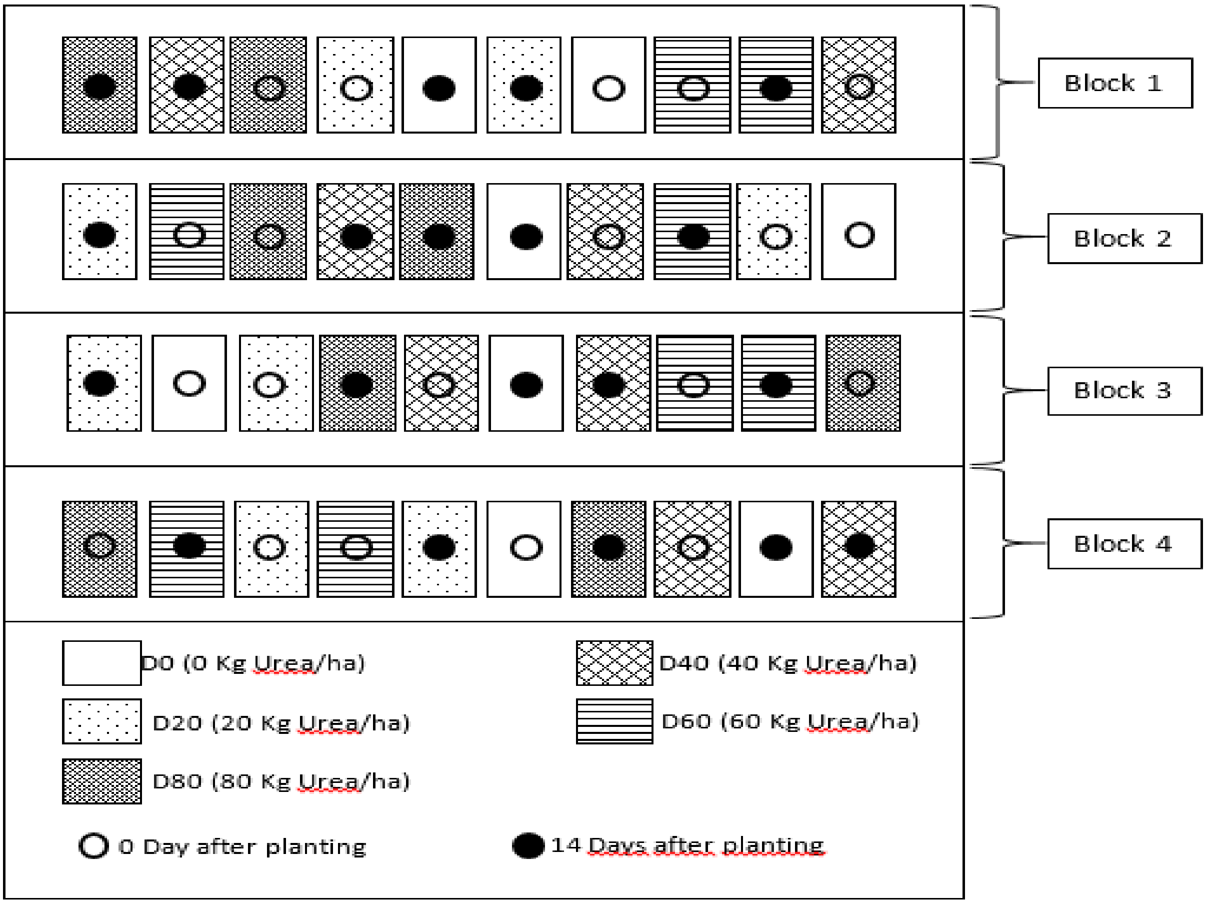
The studies were carried out in Nigeria and Benin Republic from June 2015- January 2016. In Benin Republic, the trial was established in one location at the Northern Agricultural Research Center fields (CRA Nord) located in INA, Bembèrèkè District in the department of Borgou. INA Agricultural Research Station. The climate of this location soudanian with one rainy season (May-October). In Nigeria, locations representing the forest zone (Akanran, Ilesha and Ile- Ife) and the savanna zone (Araromi and Ogbomosho) were chosen for the agronomic. The savanna and rainforest ecologies differ in terms of vegetation and quantity of rainfall per year. The coordinates of the sites are given in Table 1.

Table 1: Location and Coordinates for the field experiments.

Location	Coordinates	Altitude	Agro-ecology
INA, Bembèrèkè District	9° 95 N, 2°72 E .	254 m	Dry Savanna
Akanran	07° 18' 94" N, 003° 59' 44"E	160 m	Humid savanna
Araromi	07° 54' 67" N, 004° 08' 34"E	285 m	Humid savanna
Ogbomosho	08° 7' 42.06" N, 004° 15' 10.09" E	310 m	Humid savanna
Ilesha	07° 31.335' N, 004° 33.514' E	256 m	Humid forest
Ile-Ife	07° 29' 21.9" N 004° 34' 17.3" E	220m	Humid forest

In Nigeria, *Solanum macrocarpon* (Igbagba) and *Amaranthus viridis* (Tete abalaye) were planted by drilling on 3 m x 2 m (6m^2) raised beds at the rate of 4 small tea spoons per bed at row intervals of 10 cm while in Benin Republic, the bed size was also 6 m^2 but of 6 m x 1 m dimension. The seeds were first treated with Seed-Dress® for protection against soil-borne and seed-borne pathogens and thereafter mixed with ash to ensure even spread. In Nigeria, the *Telfairia occidentalis* (ugu) was planted at a spacing of 50 cm by 50 cm while in Benin Republic *Ocimum gratissimum* was planted by 30 cm by 30 cm. Basal application of organic fertilizer (purchased from Sunshine Fertilizers, Akure-Nigeria and CARDER in Benin) was made to all the beds at the rate of 5 tons/ha except for the NiCanVeg technology (80 kg urea-N/ha). The field was laid out in a randomized complete block design (RCBD) in four replications consisting of four rates of urea-N (46% N) application consisting of control (0), 20, 40, 60 and 80 kg urea-N/ha. Each block was separated by a path of 2 m while adjacent beds were separated by a path 1 m between beds. On each N application, we imposed two timings of fertilizer application: first dose application was done by spot placement on the day of planting while the second N application was done two weeks after planting. Therefore there were 40 experimental plots per vegetable (Figure 1).

Figure 1: Experimental design



3.2 Vegetables materials

For the purpose of our studies we tested three indigenous vegetables in each country based on the explanation that we offered in our first technical report. Table 2 below shows the types of vegetables that were evaluated in each country. The management practices that were imposed on each vegetable are explained in Table 3.

Table 2: The types of vegetables evaluated in each country.

	English name	Local names	Status	Evaluation
Amanranthus cruentus	Amaranth	Tete atetedaye in Nigeria, Fotete in Fongbe Benin)	Popular in Nigeria and Benin.	Nigeria and Benin
Solanum macrocarpon	Eggplant	Igbagba in Nigeria, Gboma in fongbe Benin Republic	Popular in Nigeria and Benin.	Nigeria and Benin
Telfairia occidentalis	Fluted pumpkin	Ugu in Nigeria	Popular in Nigeria only	Nigeria
Ocimum gratissimum	Scent leaf, parsely	Tchiayo in Fongbe	Popular in Benin only	Benin

Table 3: Management Practices on the indigenous vegetables

	Amaranthus cruentus	*Solanum macrocarpon*	*Ocimum gratissimum*	*Telfairia occidentalis*
Field planting	Seeds were first impregnated with seed treatment and then mixed with ash. Planting was done by direct seeding/drilling at Nigeria locations while at Benin location, seedlings were first raised in the nursery and transplanted to the main field at 4 weeks after sowing.	Seeds were first impregnated with seed treatment and then mixed with ash. Planting was done by direct seeding/drilling at Nigeria locations while at Benin location, seedlings were first raised in the nursery and transplanted to the main field at 6-8 weeks after sowing.	Evaluated only in Benin. Seeds were first impregnated with seed treatment and then mixed with ash. Planting was done by direct seeding/drilling at Benin location, seedlings were first raised in the nursery and transplanted to the main field at 6-8 weeks after sowing.	Evaluated only in Nigeria. Seeds were first mixed with seed treatment. Planting was done by direct seeding at Nigeria locations. Planting was done at a spacing of 50 cm x 50 cm.
Planting spacing	In Benin, seedlings were transplanted at 20 cmx 20 cm while in Nigeria direct drilling was done at 10 cm row interval. Optimized population of 550 plants/bed was used in Nigeria while 186 plants/bed was used in Benin.	In Benin seedlings were transplanted at 30 cm x 30 cm while in Nigeria direct drilling was done at 20 cm row interval. Optimized population of 250 plants/bed was used in Nigeria while 84 plants/bed was used in Benin.	In Benin seedlings were transplanted at 30 cm x 30 cm This gave a population of 84plants/bed or 111,111plants/ha	In Nigeria seed were directly planted at 50 cm x 50 cm. This gave a population of 35 plants/bed
Fertilizer application	Determined by the applicable dose of urea fertilizer, applied in two doses (at planting or 5 days after transplantation and at 14 days after transplantation)			

Crop management	Dry season (Sprinkler irrigation), Rainy season is scheduled for June 2016 Regular manual weeding and second hoeing for transplanted fields.			
Harvest	In Nigeria, first harvest was done at 28 days after sowing followed by two other sequential harvests while in Benin harvesting commenced at 4-5 weeks after transplantation and the others 2 weeks after	In Nigeria, first harvest was done at 35 days after sowing followed by twelve (12) other sequential harvests at 15 days interval while in Benin harvesting commenced at 4-6 weeks after transplantation and the other was 4 weeks after.	In Benin, staggered (2-5 harvest) from 4-6 weeks after transplantating and the others 4– 6 weeks after	In Nigeria, first harvest was done at 35 days after sowing followed by twelve (12) other sequential harvests at 15 days interval.

3.3 Data collection:

For purpose of this report, we are presenting data on leaf yield (biomass), soil analyses results and quality parameter of the different vegetables. The leaf yield constitute the economic product of the vegetables. For record purposes, we also collected data on plants height, number of leave per plant; weekly, soil samples (0-20 cm) taken at beginning and at the end for soil nutrients status monitoring: total N, total P, total K; CO content), soil moisture; nutrients loss (water drainage).

3.4 Statistical analysis

After verification of normality of the collected data, they were subjected to analysis of variance (ANOVA) with all treatments and four replications. In some cases, polynomial and linear regression analyses were performed to model leafy vegetable response to fertilizer levels by taking the means of the two urea application dates.

4 Results

4.1.1 Soil Properties

The mean macro-nutrient contents of the soil of the field trial sites in the humid forest and humid savanna at the commencement of the study are presented Tables 4, 5 and 6b. The soils are moderately rich in basic cations with Ca predominating. This is because the sites were recently recovered from vegetative fallow. These nutrients are readily leached because of the high intensity rainfalls that is prevalent in addition to plant extraction of the nutrients from the soil. The soil in the dry savannah zone is acidic, poor in organic carbon with a low nitrogen and potassium content (Table 6b).

Table 4: Macronutrient contents of soil in Humid forest location after application of organo-mineral fertilizer and urea

Urea-N Rates	Igbagba (*Solanum macrocarpon*)			Ugu (*Telferai occidentalis*)			Tete (*Amaranthus spp*)		
	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
0	1.56	0.54	0.024	9.15	0.54	0.18	1.75	0.51	0.021
20	NA	NA	NA	8.55	0.70	0.11	1.54	0.67	0.020
40	1.36	1.06	0.031	8.18	0.41	0.026	1.67	0.99	0.029
60	1.41	0.89	0.029	7.98	0.58	0.019	1.55	0.72	0.031
80	0.69	0.49	0.029	5.95	0.39	0.014	1.69	0.54	0.028
Mean	1.25	0.74	0.028	8.16	0.52	0.017	1.25	0.74	0.028

Table 5: Macronutrient contents of soil in Humid Savanna location under different vegetables after the application of organo-mineral fertilizer and urea

Urea-N Rates	Ugu (*Telferai occidentalis*)			Igbagba (*Solanum macrocarpon*)			Tete (*Amaranthus spp*)		
	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
0	0.59	0.034	0.06	1.04	0.018	0.32	1.52	0.17	0.04
20	1.27	0.026	0.63	3.26	0.023	0.11	1.61	0.58	0.03
40	1.93	0.024	0.74	4.61	0.022	0.50	0.69	0.54	0.03
60	2.32	0.025	0.64	3.75	0.023	0.51	1.26	0.59	0.03
80	2.13	0.022	0.64	3.75	0.023	0.25	1.26	0.56	0.02
Mean	1.65	0.026	0.41	4.42	0.022	0.32	1.32	0.49	0.03

Table *6a*: Soil physical and chemical characteristics in the dry Savanna zone

Soil physical properties (0-0.2 m)		Soil chemical properties (0-0.2 m)	
Sand (%)	83.1	pH-H_2O	5.2
Silt (%)	12.6	Organic C (%)	0.5
Clay (%)	4.3	Total N (%)	0.03
Texture	Sandy loam	Total P (%)	0.01

Table 6b: Soil physical and chemical characteristics in the dry savanna (Ina, Benin)

Parameters	Soil depth (0-20 cm)	Soil depth (20-40 cm)	Cattle manure
Soil texture			
Sand (%)	82.43	76.76	-
Silt (%)	3.77	9.04	-
Clay (%)	13.81	14.20	-
Texture	Sandy loam	Sandy loam	-
Soil chemical properties			
pH-H2O	4.65	4.77	7.5
Electric Conductivity (µs)	173.4	142.6	1780.5
Organic Carbon (%)	0.368	0.274	10.7
Total N (%)	0.06	0.051	0.8
NH4-N (%)	0.00082	0.00048	0.002
NO3-N (%)	0.001923	0.001758	0.011
Total P (%)	0.03375	0.03135	0.15
Available P (%)	0.001702	0.000827	0.05
Total K (%)	-	-	0.9
Exchangeable K (%)	-	-	-

4.1.2 Fresh leaf yield

The *Amaranthus* leaf yields at both the Nigerian rainforest and savanna locations (2.5-4.0 tons/ha) significantly out-yielded the *Amaranthus* planted in Benin Republic (maximum of 1.63 kg/m²). For S. macrocarpon, the leaf yield in Nigeria is 3.2-8.3 kg/m² during three successive harvests, across the urea-N rates while in Benin the leaf yield is 3.26 kg/m².

Specifically in Nigeria, The fresh vegetables shoot yields were significantly higher in the savannah locations compared to forest locations in both rainy and dry seasons. The lower yields in the forest locations may be due to high cloud cover resulting in a much lower solar radiation thus reducing photosynthetic activities of the vegetables in the forest zone compared to the savannah locations. The cumulative fresh shoot yield of Amaranthus viridis increased from 2.5 kg/m² and 4.0 kg/m² under control reaching a maximum of 4.9 kg/m² and 8.70 kg/m² under 60 kg/ha of urea-N application respectively in the forest location and savannah sites (Figs. 2 and 5). Similar trends were also observed with Igbagba and Ugu (Figs. 3 and 4; 6 and 7). However the NiCanVeg innovation was not significantly different from the MicroVeg innovation for ugu in the forest zone during the wet season trial. The microdosing innovation when compared to the NiCanVeg technology resulted in higher yield when 40 kg/ha urea-N application was compared with optimum 80 kg/ha urea-N of the NiCanVeg technology for the three vegetables in both seasons and across the five locations studied.

In Benin, results show that the cumulative fresh shoot yield of *Amaranthus cruentus* increased from 1.31 kg/m² (control) to 2.55 kg/m² (60 kg/ha Urea-N) during the wet season (fig 2) and from 1.08 kg/m² (control) to 1.34 kg/m² (60 kg/ha Urea-N) during the dry season (fig. 5). The results showed that in the dry season the cumulative fresh shoot yield increased from 2.49 kg/m² (control) to 3.27 kg/m² (60 kg/ha Urea-N) for *Solanum macrocarpon* and from 2.39 kg/m² to 2.72 kg/m² (40 kg/ha Urea-N) for *Ocimum gratissimum* (Figs. 6 and 8).

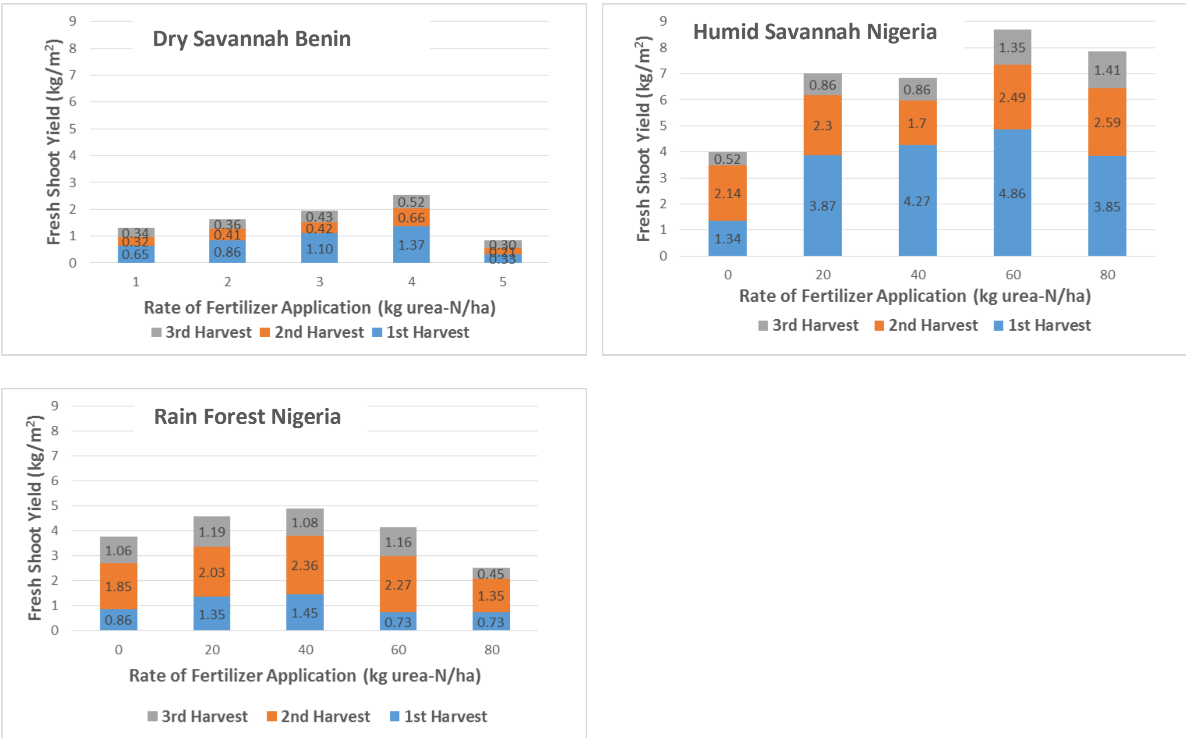


Fig 2: **Fresh shoot yield** of **Tete** (*Amaranthus sp*) from Forest and Humid Savannah locations in Nigeria and from Dry Savannah location in Benin response to fertilizer microdosing during the **wet season** (the 80 kg/ha represents the NiCanVeg technology)

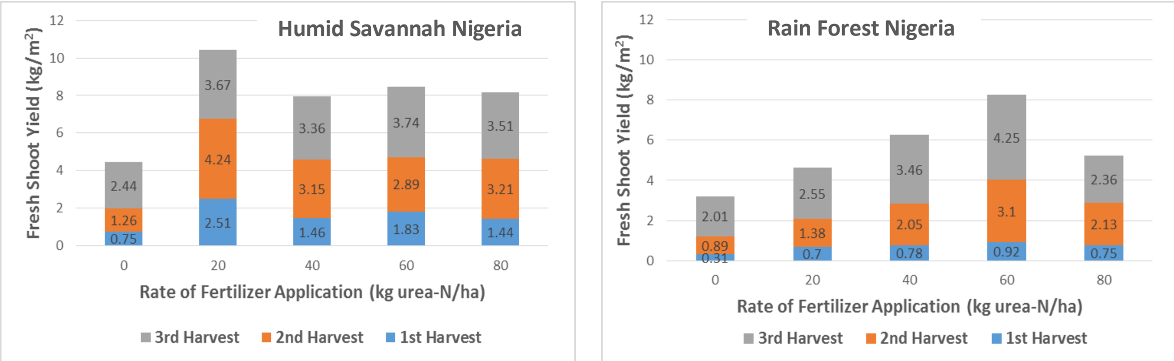


Fig 3: **Fresh shoot yield** of **Igbagba** (*Solanum macrocarpon*) from Rain Forest and Humid Savannah locations in Nigeria in response to fertilizer microdosing during the **wet season** (the 80 kg/ha represents the NiCanVeg technology)

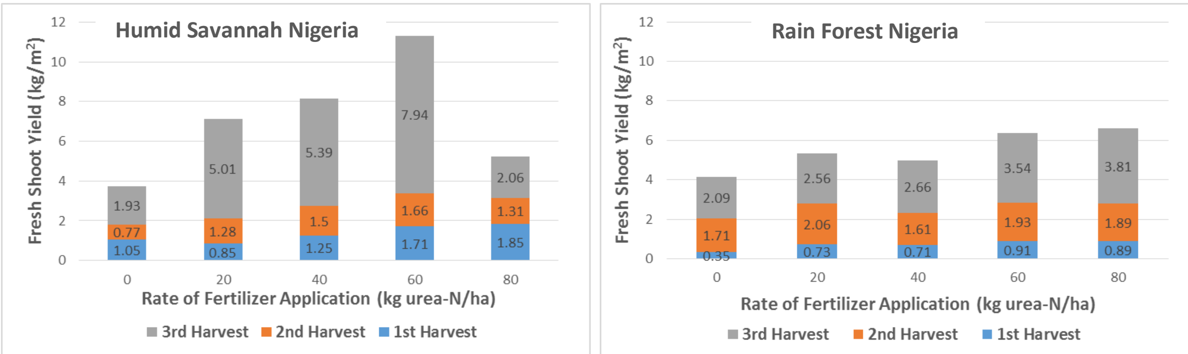


Fig 4: **Fresh shoot yield** of **Ugu** (*Telferia occidentalis*) from Rain Forest and Humid Savannah locations in Nigeria in response to fertilizer microdosing during the **wet season** (the 80 kg/ha represents the NiCanVeg technology)

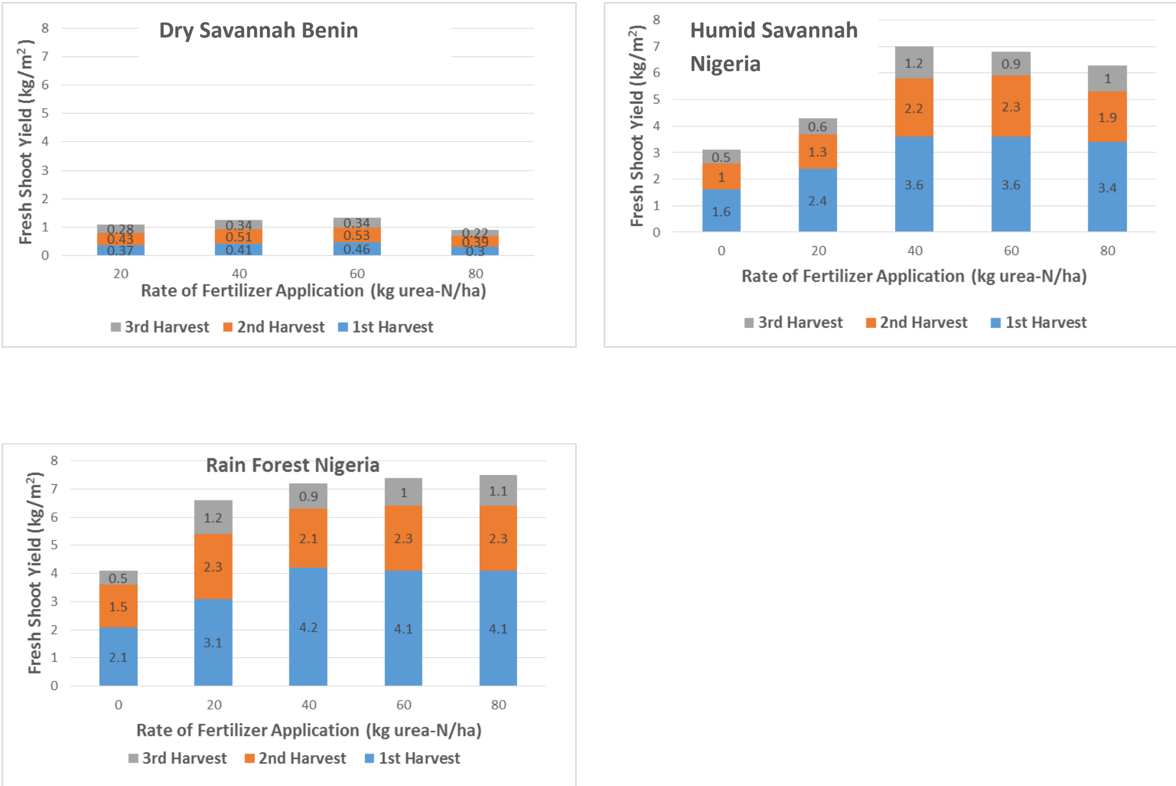


Fig 5: **Fresh shoot yield** of **Tete** (*Amaranthus viridis*) from Rain Forest and Humid Savannah locations in Nigeria and from Dry Savannah location in Benin response to fertilizer microdosing during the **dry season** (the 80 kg/ha represents the NiCanVeg technology)

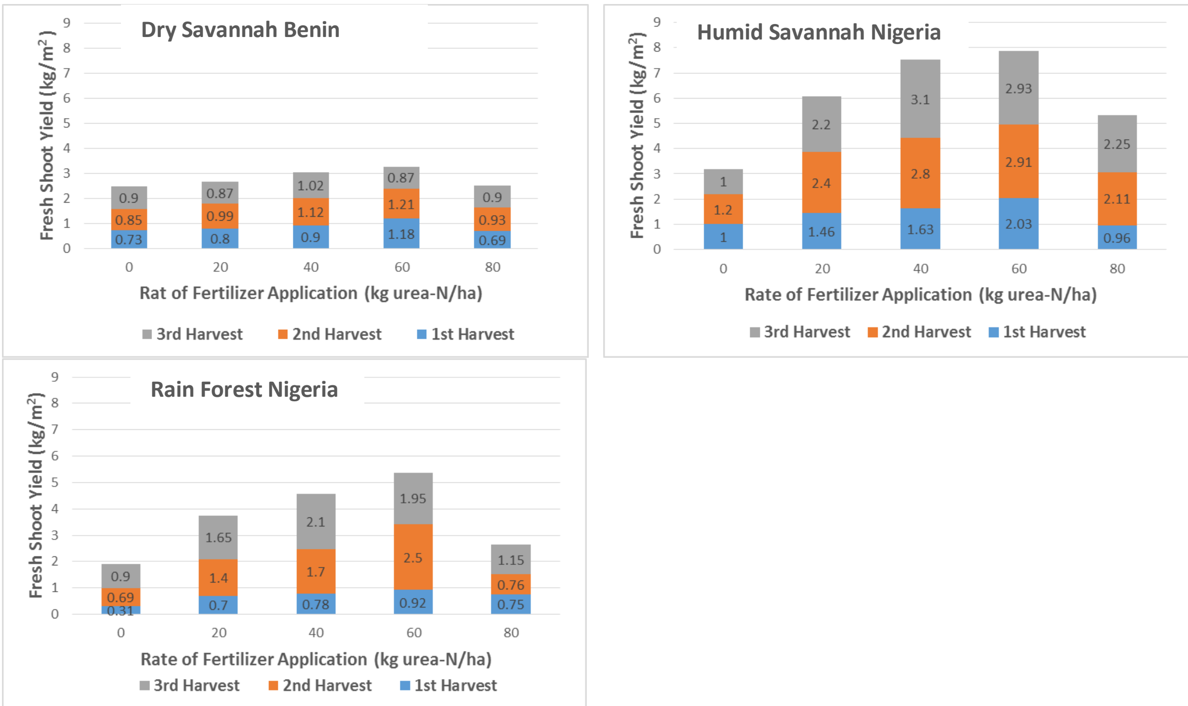
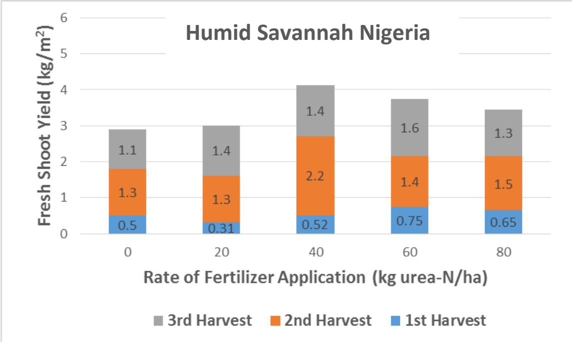


Fig 6: **Fresh shoot yield** of **Igbagba** (*Solanum macrocarpon*) from Rain Forest and Humid Savannah locations in Nigeria and from Dry Savannah location in Benin response to fertilizer microdosing during the **dry season** (the 80 kg/ha represents the NiCanVeg technology)



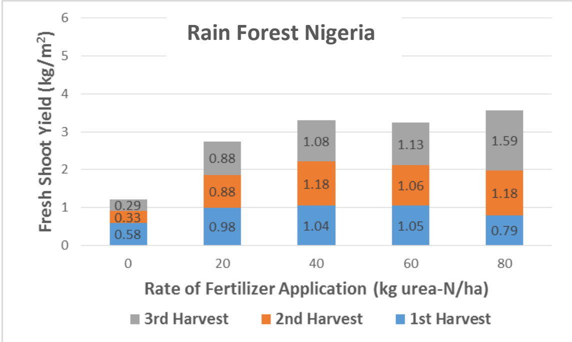


Fig 7: **Fresh shoot yield** of **Ugu** (*Telferia occidentalis*) from Rain Forest and Humid Savannah locations in Nigeria in response to fertilizer microdosing during the **dry season** (the 80 kg/ha represents the Nicanveg technology)

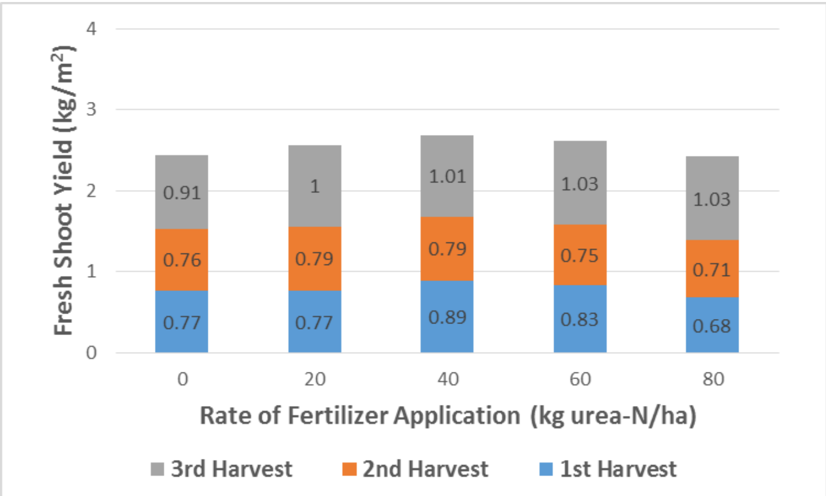


Fig 8: **Fresh shoot yield** of Tchiayo (*Ocimum gratissimum*) from dry Savannah location in Benin response to fertilizer microdosing during the **dry season** (the 80 kg/ha represents the NiCanVeg technology)

4.1.3 Greenness Index

Vegetables are preferably sold and consumed while still fresh and in full greeness. The market values of vegetables therefore depend on the freshness and greenness. The SPAD index is a measure of the greenness of plant leaves and it is used to estimate the chlorophyll contents of plant leaves. Tables 4-6 show the effects of fertilizer micro-dosing on the leaf greenness of the three vegetables. The leaf greenness expectedly increased with the increased rate of urea-N application. Vegetables that received N application were significantly greener than the control (unamended) vegetables across locations and seasons with no significant differences amongst the vegetables grown on amended soils. However, the vegetables grown in the savanna were greener than in the forest zones. This again may be due to higher insolation in the savanna compared to the forest zone. This is further confirmed by the results from the dry season trials in which the vegetables were significantly greener than the wet season vegetables.

Table 6: Greenness index (in SPAD units) of ugu (*Telferia occidentalis*) in response to fertilizer micro-dosing treatments in the wet season in two agro-ecological zones of southwest Nigeria as influenced by time of application.

Urea_N	**Savanna**		**Forest**	
Rates kg ha^{-1}	Fert. at Planting	Fert. at 2 weeks after planting	Fert. at Planting	Fert. at 2 weeks after planting
0	45.90	46.45	46.68	47.45
20	47.01	50.18	48.88	49.94
40	49.50	50.62	52.29	49.08
60	46.69	49.53	54.68	59.11
80	49.11	52.06	55.57	6a.13

Table 7: Greenness index (in SPAD units) of Igbagba (*Solanum macrocarpon*) in response to fertilizer micro-dosing treatments in the wet season in two agro-ecological zones of southwest Nigeria as influenced by time of application.

Urea_N	**Savanna**		**Forest**	
Rates kg ha^{-1}	Fert. at Planting	Fert. at 2 weeks after planting	Fert. at Planting	Fert. at 2 weeks after planting
0	56.38	57.64	22.18	29.58
20	58.09	56.92	28.73	29.23
40	58.05	57.60	38.63	37.03
60	57.31	59.93	38.55	38.98
80	60.68	59.31	39.05	40.60

Table 8: Greenness index (in SPAD units) of Tete Abalaye (*Amaranthus virides*) in response to fertilizer micro-dosing treatments in the wet season in two agro-ecological zones of southwest Nigeria as influenced by time of application.

Urea_N	Savanna		Forest	
Rates kg ha^{-1}	Fert. at Planting	Fert. at 2 weeks after planting	Fert. at Planting	Fert. at 2 weeks after planting
0	36.81	39.92	30.95	32.13
20	44.13	40.07	32.70	30.98
40	40.68	40.68	32.18	31.25
60	40.05	40.96	31.00	30.65
80	40.88	42.17	29.05	29.85

4.1.4 Phosphorous Iron and Zinc contents of soil and vegetables

The phosphorous, iron and zinc contents of the soil and the vegetables (*Igbagba* and *Tete abalaye*) in response to fertilizer trials are presented in Table 7, 8 and 9, respectively. The P contents of *Igbagba* was significantly higher than *Tete* at all urea-N rates, showing the former to have preferential affinity for extracting P from the soil. The P contents of the vegetables however did not respond to the different rates of urea-N application simply because urea is not a source of P. The Fe contents of *Igbagba* was again significantly higher compared to *Tete* but did not significantly vary with rates of applied urea-N. The Zn contents in plant tissues however did not differ significantly between *Igbagba* and *Tete* and also did not respond to rates of urea-N treatment.

Table 9: Phosphorous contents of soil and tissues of Igbagba (*Solanum macrcarpon)* and Tete Abalaye (*Amaranthus virides*) in response to fertilizer micro-dosing treatments in the savanna agro-ecological zones of southwest Nigeria.

	Igbagba		*Tete*	
Urea_N Rates kg ha^{-1}	Soil P	Tissue P	Soil P mg kg^{-1}	Tissue P
0	11.14	50.43	5.89	36.05
20	13.14	60.63	9.72	32.61
40	24.29	57.47	15.33	32.97
60	21.84	54.97	10.91	27.82
80	19.00	56.27	9.35	24.22

Table 10: Iron contents of soil and tissues of Igbagba (*Solanum* macrcarpo) and Tete Abalaye (*Amaranthus virides*) in response to fertilizer micro-dosing treatments in the savanna agro-ecological zones of southwest Nigeria.

	Igbagba		*Tete*	
Urea_N Rates kg ha^{-1}	Soil Fe	Tissue Fe mg kg^{-1}	Soil Fe	Tissue Fe
0	13.03	439	39.11	391
20	8.50	514	37.47	379
40	8.23	470	48.81	386
60	9.54	481	56.77	379
80	16.09	478	87.09	306

Table 11: Zinc contents of soil and tissues of Igbagba (*Solanum* macrcarpo) and Tete Abalaye (*Amaranthus viridis*) in response to fertilizer micro-dosing treatments in the savanna agro-ecological zones of southwest Nigeria.

	Igbagba		*Tete*	
Urea_N Rates kg ha^{-1}	Soil Zn	Tissue Zn	Soil Zn mg kg^{-1}	Tissue Zn
0	0.80	36.12	2.08	38.96
20	3.20	60.19	2.87	42.90
40	2.26	35.98	2.82	40.75
60	2.58	42.86	4.09	36.38
80	1.95	39.50	3.42	33.86

Table 10 shows a matrix ranking of the different rates of urea-N based on vegetable yield, quality as measured by its greenness and the micronutrient status along with the cost of fertilizer and its application. The 40 kg/ha urea-N rate gave the highest value of 19 followed by 60 kg/ha rate. There was no significant influence of timing of fertilizer yield. Application of fertilizer at planting is therefore recommended since it will save the cost of hiring extra labour for the sole purpose of fertilizer application if it has to be applied later. Commulatively, the results show that urea fertilizer when applied at rates ranging from 40 to 60 kg N ha^{-1} was optimum for vegetable leaf yield in the study locations. This must however be augmented with basal application organic manure at 5 t ha^{-1}.

Table 12: Matrix for computation of rate of urea-N required for optimum production of indigenous vegetables in the forest and savanna agro-ecologies of Nigeria.

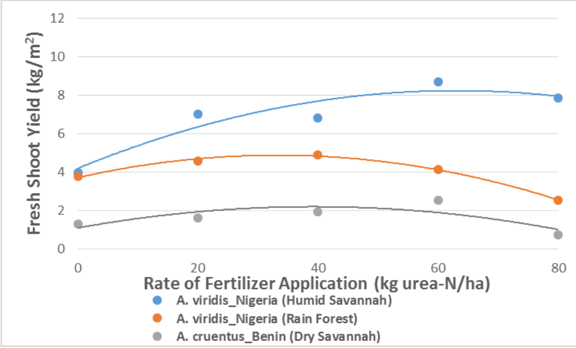
Rate of urea-N (kg/ha)	Yield	Leaf quality	Nutrient content	Fertilizer cost	Labour cost	**Aggregate**
0	1	1	1	5	5	**13**
20	2	3	4	4	4	**17**
40	4	5	4	3	3	**19**
60	5	5	4	2	2	**18**
80	3	4	4	1	1	**13**

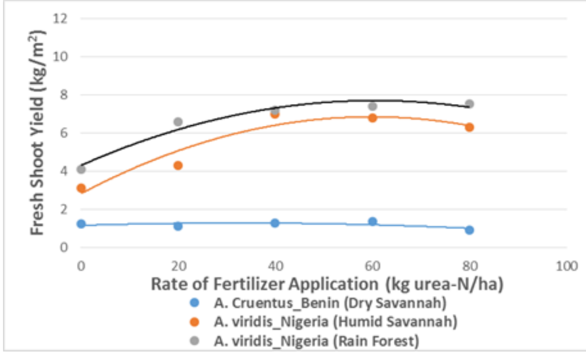
4.1.5 Optimum urea application rates for vegetable

The response of vegetable to urea application can result in a polynomial regression of the form: $\mathbf{y = ax^2 + bx + c}$; with a; b and c, coefficients. Figure 8 shows this response for each vegetable. In Nigeria, an optimum of 40-60 kg urea-N rate was established for the three vegetables during two cycles of planting. In Benin the dose of 40 kg/ha showed the highest yield for *Amaranthus*. For *Solanum macrocarpon* and *Ocimum gratissimum* the best yield was obtained for the dose of 60 kg/ha. The residual macronutrients in the soils after three cycles of vegetable harvest was not significantly different between the micro-dose plots and the traditional fertilizer applications method (Tables 13 & 14). This shows that fertilizer micro-dosing can be used to sustainably produce these vegetables when combined with organic manure at the rate of 5 t per ha.

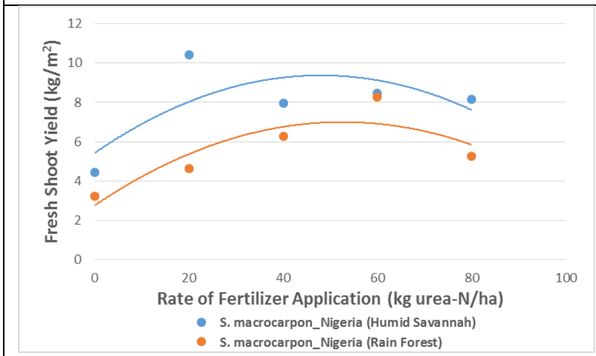
Wet season	Dry season

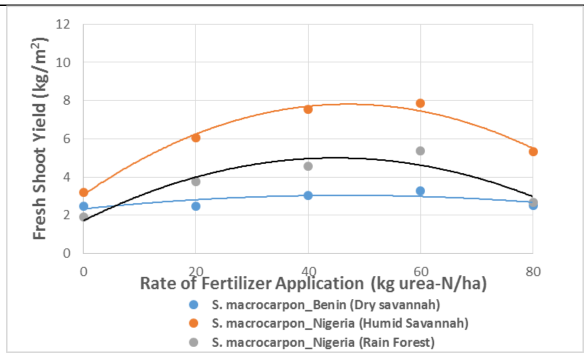
Amaranthus



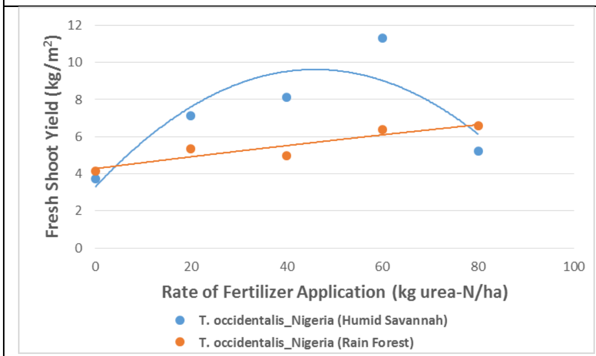


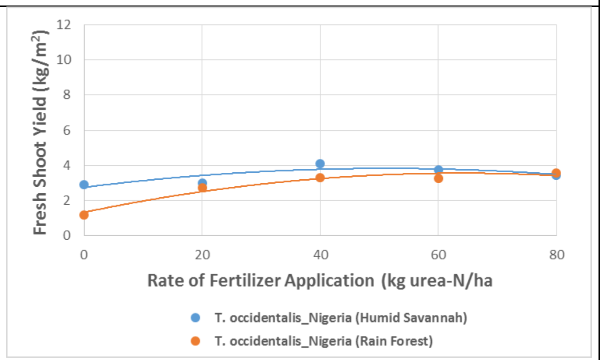
Solanum macrocarpon





Telferia occidentalis





Ocimum gratissimum

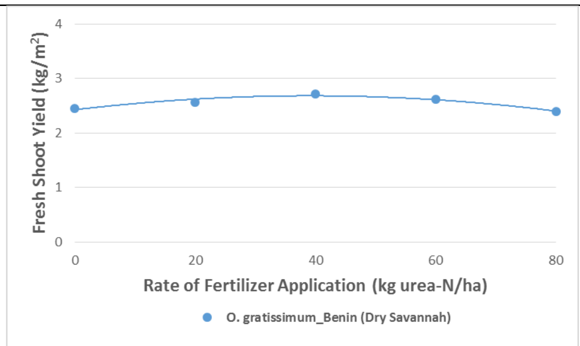


Figure 9: Vegetable from Rain Forest and Humid Savannah locations in Nigeria and from Dry Savannah location in Benin in response to fertilizer microdosing during the dry season (the 80 kg/ha represents the Nicanveg technology)

Table 13: Residual macronutrient contents (cmol/kg soil) of soil in Humid forest location after vegetable harvest

Urea-N Rates	Igbagba (*Solanum macrocarpon*)			Ugu (*Telferai occidentalis*)			Tete (*Amaranthus spp*)		
	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
0	3.29b	0.57a	0.30a	5.14a	0.48a	0.23b	4.74a	0.43a	0.21a
20	NA	NA	NA	5.52a	0.49a	0.34a	5.02a	0.39a	0.22a
40	3.05b	0.50a	0.40a	5.70a	0.50a	0.28b	4.87a	0.49a	0.34a
60	3.25b	0.48a	0.43a	5.56a	0.49a	0.26b	4.74a	0.47a	0.24a
80	4.24a	0.46a	0.34a	5.14a	0.45a	0.20b	5.11a	0.43a	0.22a
Mean	3.46	0.50	0.37	5.41	0.47	0.26	5.21	0.42	0.23

Table 14: Residual macronutrient contents of soil in Humid Savanna location after vegetable harvest

Urea-N Rates	Ugu (*Telferai occidentalis*)			Igbagba (*Solanum macrocarpon*)			Tete (*Amaranthus spp*)		
	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
0	2.88b	0.43a	0.11b	2.91b	0.35b	0.13a	3.87b	0.56a	0.15a
20	4.95a	0.41a	0.20a	2.97b	0.52ab	0.23a	5.94b	0.55a	0.21a
40	4.18a	0.39a	0.19a	3.14b	0.47ab	0.18a	7.60a	0.53a	0.17a
60	2.79b	0.40a	0.19a	3.71ab	0.48ab	0.17a	7.06a	0.56a	0.14a
80	2.73b	0.39a	0.21a	4.42a	0.59a	0.16a	3.05c	0.65a	0.15a
Mean	3.51	0.40	0.18	3.43	0.48	0.17	5.05	0.57	0.16

4.1.6 Partial nutrients balance

Partial nutrient balance computation (nutrient input minus vegetable leaves nutrient uptake) showed that continuous vegetable (Solanum, Telfairia, Amaranthus and African basil) production without manure depleted the soil in N (-268.3 to -30.8 to kg/ha for D40, -195.0 to -4.5 kg/ha for D60), P(-65.0 to -18.3 for D40 and –286.0 to -18.7 kg/ha for D60) and K (-336.3 to -2.3 to kg/ha for D40, -2703.2 to -2.4 kg/ha for D60), although soil nutrient mining was moderate with African Basil.Table 15: Partial nutrients balance with continuous microdosing without manure application in the dry savanna zone (Ina, Benin)

	D40		
	N (kg ha^{-1})	**P** (kg ha^{-1})	**K** (kg ha^{-1})
Amaranthus	-101.07±121.11	-46.9±20	-336.35 ±135.79
Solanum	-261.26±80.9	-65.04±5.65	-329.3±79.11
African Basil	-30.81±12.42	-18.26±1.51	-2.29±0.3
Telfairia	-268.26±60.3	-60.04±5.75	-319.3±65.24
	D60		
Amaranthus	-53.90±98.03	-286.02±80.99	-2703.19±853.63
Solanum	-195.03±75.92	-61.76±18.24	-325.93±65.45
African Basil	-4.46±2.73	-18.67±1.13	-2.40±0.13
Telfairia	-175.25±65.30	-66.65±20.14	-330.41±75.50

The combined application of fertilizer micro-dosing and manure (5t/ha) in continuous production during one year of Amaranth (4 cycles), Telfairia (one cycle), Solanum (2 cycles) and African Basil (2 cycles) led to a positive N balance under amaranth (+60.8 kg/ha for D60) and African Basil (7.4 and 33.8 kg/ha for D40 and D60 respectively). K and P mining is corrected only when manure (5t.ha) is renewed at each crop cycle or higher amount is applied instead (not shown).

4.1.7 Water use and water use efficiency

The results show no significant difference between the urea doses and the application dates. Similar results were reported for interaction between urea doses and application dates where WU was an average of 377.1 mm. Fresh biomass yield weight and biomass dry matter increased at an average rate of 31 kg ha^{-1} and 5 kg ha^{-1} per 1 mm of water used, respectively in the dry savanna (Fig. 10). In the humid forest fresh biomass of *Amaranthus* and *Solanum* increased at an average rate of 27 kg ha^{-1} and 36 kg ha^{-1} respectively and by 32 kg ha^{1} and 48 kg ha^{-1} in the same order in the humid savanna (Tables 11-14).

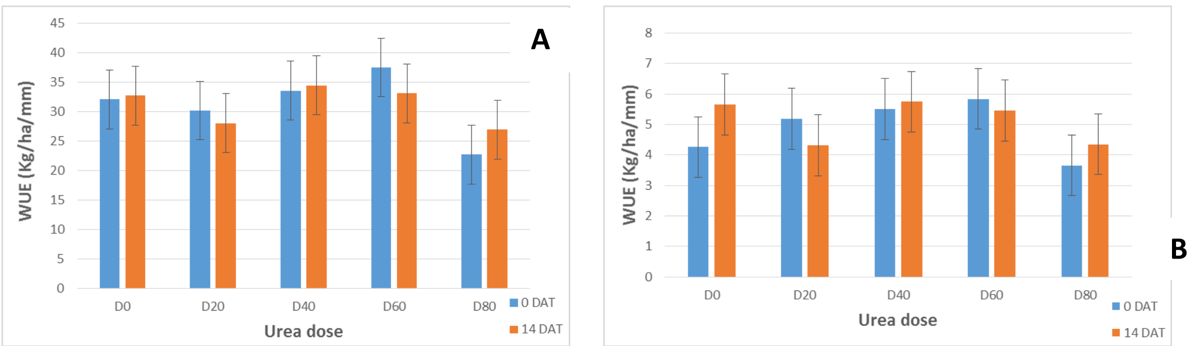


Figure 10: Water use efficiency of tete (Amaranthus cruentus) (A) Fresh biomass yields (B) Biomass dry matter from Dry Savannah location in Benin during the Dry season.

Table 16: Crop evapotranspiration and crop coefficient of *Solanum macrocarpon* in Humid forest location

Treatments kg urea N/ha	ETc(ini)	ETc (mid)	ETc(late)	Kc (ini)	Kc (mid)	Kc (late)	WUE Kg/ha/mm water
	—— mm/day ——						
0	0.88c	2.33b	1.57a	0.33c	1.07c	0.77a	15.84b
40	1.88a	4.12a	1.73a	0.70a	2.64a	0.85a	20.13b
80	0.77c	1.84c	1.67a	0.29c	1.18c	0.82a	36.26b
160	1.37b	2.50b	2.42a	0.51b	1.87b	0.79a	21.81b
Mean	1.23	2.70	1.85	0.45	1.69	0.81	23.51
Std.dev.	0.54	0.70	0.32	0.10	0.20	0.08	10.67
Minimum.	0.56	0.90	0.59	0.31	0.27	0.16	8.66

Maximum.	2.23	7.38	2.76	1.62	2.97	1.46	42.88

* Means followed by the same letters in the same column are not significantly different (P = 0.05) according to Duncan`s Multiple Range Test.

Treatments	ET_C(ini)	ET_C(mid)	ET_C(late)	Kc(ini)	Kc(mid)	Kc(late)	WUE
kg Urea N/ha		mm/day					kg/ha/mm water
0	3.12a	4.49b	0.12c	1.17a	2.89ab	0.07b	3.08b
40	3.84a	5.95a	1.76a	0.44a	03.18a	0.86a	7.28b
80	1.92a	1.78c	0.54b	0.72b	0.1.14b	0.26b	27.48a
160	3.04a	3.18bc	0.50bc	1.13a	2.04ab	0.25b	23.00a
Mean	2.98	3.85	0.73	1.12	2.31	0.36	15.21
Std dev.	0.91	1.80	0.75	0.33	1.36	0.32	11.13
Minimum	1.61	1.47	0.35	0.60	0.04	0.05	2.25
Maximum	5.00	6.19	2.22	1.89	4.76	1.09	34.77

Table 17: Crop evapotranspiration and crop coefficient of *Amaranthus viridis* in the Humid forest location.

* Means followed by the same letters in the same column are not significantly different (P = 0.05) according to Duncan `s Multiple Range Test.

Table 18: Crop evapotranspiration and crop coefficient of *Solanum macrocapon* in Humid Savanna location

Treatments kg Urea N/ha	ET_C(ini)	ET_C(mid) mm/day	ET_C(late)	Kcini)	Kc(mid)	Kc(late)	WUE kg/ha/mm water
0	1.08ab	1.68a	0.70a	0.39ab	0.84a	0.29a	49.06b
40	0.78b	0.88b	0.62a	0.28b	0.44b	0.26a	70.79a
80	1.34a	2.40a	0.73a	0.48a	1.20a	0.30a	48.53b
160	1.06ab	1.94a	0.94a	0.38ab	0.97a	0.39a	53.22b
Mean	1.06	1.72	0.75	0.39	0.86	0.31	55.40
Std dev.	0.30	0.70	0.33	0.11	0.35	0.13	11.39
Minimum.	0.55	0.57	0.26	0.20	0.28	0.11	37.87
Maximum.	1.46	2.91	1.46	0.53	1.52	0.60	73.78

* Means followed by the same letters in the same column are not significantly different (P = 0.05) according to Duncan `s Multiple Range Test.

Table 19: Crop evapotranspiration and crop coefficient of *Amaranthus viridis* in Humid Savanna location

Treatments kg Urea N/ha	ET_C(ini)	ET_C(mid) mm/day	ET_C(late)	Kc(ini)	Kc(mid)	K(late)	WUE kg/ha/mm water
0	1.21a	0.06b	0.90a	0.63b	0.02c	0.31a	19.76c
40	1.07b	0.06b	1.01a	0.33b	0.02c	0.34a	30.09b
80	0.47c	2.70a	0.65a	3.32a	1.01a	0.23a	31.96b
160	0.60c	0.27b	1.64a	0.18b	0.10b	0.57a	45.47a
Mean	1.06	0.77	1.05	1.15	0.29	0.36	31.82
Std dev.	0.70	1.16	0.74	7.52	0.43	0.26	12.17
Minimum	0.40	0.01	0.44	0.17	0.00	0.15	14.06
Maximum	2.17	2.85	3.22	19.71	1.06	1.12	53.89

* Means followed by the same letters in the same column are not significantly different (P = 0.05) according to Duncan `s Multiple Range Test.

4.1.8 Water Management

We carried out a study to compare the comparative advantages of a capillary irrigation with the sprinkler method under different methods of fertilizer applications in rain and dry cropping seasons in two locations in Nigeria between 2016 and 2017. The capillary irrigation innovation consists of PVC pipe which serves as the reservoir which is connected to a smaller pipe that serves as a node through which water moves to the crop rooting zone by capillary action (Plate 7a). The reservoir is installed deeper into the vegetable bed while the nodes protrude directly to the root zone. The reservoir is filled with water through an PVC pipe inlet (Plate 7b). The treatments are described in Table 15. The results showed a significant improvement in amaranth yield under capillary irrigation, while there was no significant difference yield between the treatments that received fertilizer by side dressing and spot application in both locations (Fig. 11). The treatments that received fertigation however yielded lower in humid forest location than other methods apparently due to loss in runoff or due to deep percolation.

The water required to produce a unit weight of amaranth was reduced from 450 L on the traditional farmers method to 200 L under the capillary innovation (Fig. 12). This translated to water saving of approximately 2.2 million L/ha in forest to an approximate 8 million L/ha in the savanna ecosystem (Fig. 13). This is of great significance for vegetable production especially during the dry season when water is usually in short supply. The capillary irrigation innovation prevented water loss by evaporation, surface runoff and deep percolation when excess water infiltrates the soil. The innovation ensures that water moves into the root zone only in response to evapotranspiration demands. The savings will be more profound if the savings in the cost of fertilizer application and nutrient loss reduction is accounted for.

Table 20: Description of the treatments used for the field experiment on capillary irrigation

Treatments	Method of Irrigation	Fertilizer rate (kg N/ha)	Fertilizer Application method
1	Sprinkler	0	NA
2	Capillary	40	Fertigation
3	Sprinkler	40	Spot
4	Sprinkler	40	Drill
5	Sprinkler	40	Fertigation
6	Sprinkler	80	Broadcast

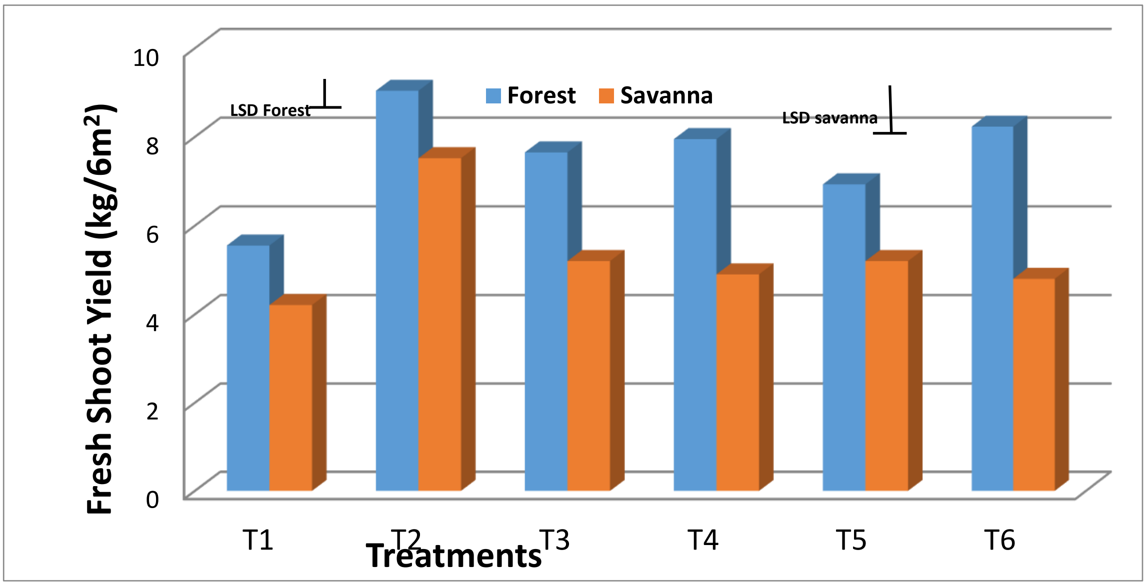


Fig. 11: Amaranth yield in response to irrigation and methods of fertilizer application in humid forest humid savanna locations (T1 = Control, T2 = Capillary + fertigation, T3 = Spot, T4 = Drill, T5 = Fertigation, T6 = Broadcast at 80 kg N/ha Irrigation by sprinkler in all except the capillary (T2))

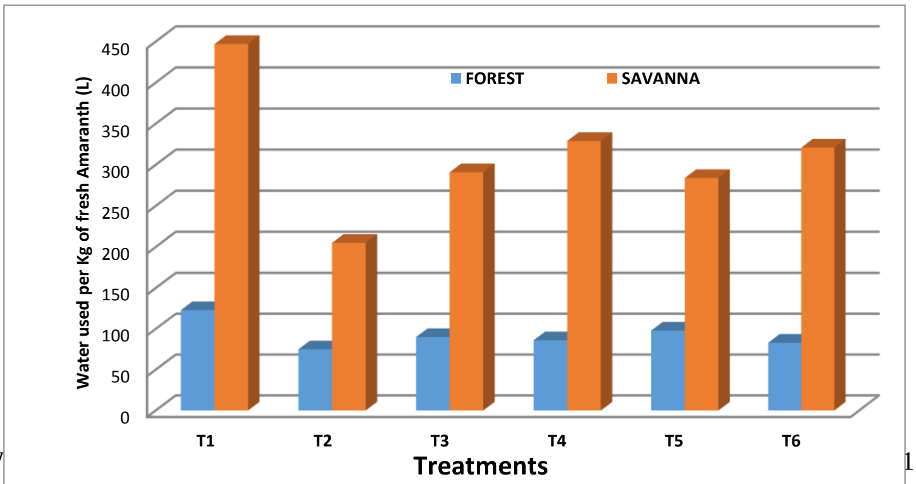


Fig. 12 : W 1 = Control, T2 = Capillary + fertigation, T3 = Spot, T4 = Drill, T5 = Fertigation, T6 = Broadcast at 80 kg N/ha Irrigation by sprinkler in all except the capillary (T2))

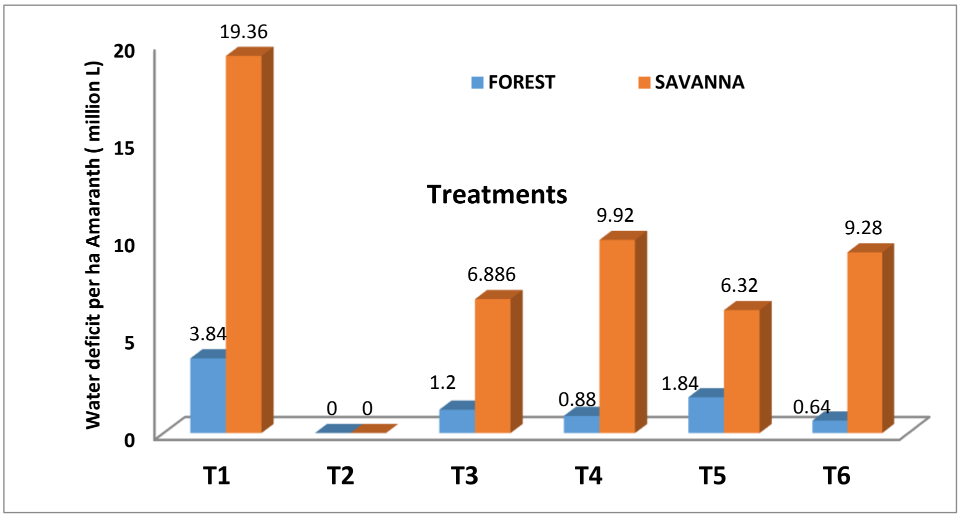


Fig 13: Additional volume of water (million Litres/ha) required by other methods compared with the capillary irrigation ((T1 = Control, T2 = Capillary + fertigation, T3 = Spot, T4 = Drill, T5 = Fertigation, T6 = Broadcast at 80 kg N/ha Irrigation by sprinkler in all except the capillary (T2))

Conclusion

For the three agro-ecologies (rainforest, dry and humid savanna) the 40-60 kg/ha urea-N rate is the optimum which significantly favoured leaf yield, greenness and nutrient contents of the three vegetables while timing of application had no significant influence on leaf yield. Renewal of this rate is recommended after three harvests for the longer cycled vegetables i.e Igbagba, Ugu and Tchyao. The study also showed that fertilizer micro-dosing at rates between 40 and 60 kg/ha did not any negative impact on soil nutrient contents. However, a basal application of organic manure at a minimum rate of 5 t/ha is recommended to sustain soils nutrient and physical properties. These results are to be confirmed by trials during a second year time replication. Capillary irrigation innovation has shown a good potential to significantly reduce the volume of irrigation water required for vegetables. Moreover, it reduces the drudgery involved in irrigation and it is also more women friendly.

Annex 1: Nigeria Agronomy Trials

Plate 1: (a) Plot layout at Ogbomosho and (b) harvesting of Igbagba at Ilesha agronomy trial site (in the background are marketers)

Plate 2: Weighing and recording of the harvest of Tete at the Ogbomosho site

Plate 3: A Microveg Field Officer determining the greenness index of ugu in Ile-Ife agronomy trial site

Plate 4: Layout of the field at Akanran

Annex 2: Benin Experiments

Plate 5: Overview of the experimental site in Ina, Republic of Benin

Plant high measurement

Urea weighing for application

	 
Overview of the Amaranthus layout	Micro-lysimeters for leaching follow
	
Amaranthus seed harvest	Solanum fresh biomass harvest

Annex 3: Nigeria Water Management Experiments

Plate 6: A Micro-lysimeter system for crop water use determination in (a) Ife and (b) Saaki

Plate 7: (a) Capillary irrigation system showing the parts; (b) Training of women farmers on the capillary irrigation system

Plate 8: Harvesting of matured vegetables in (a) forest location and (b) savanna location