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Evaluation of the efficacy of Aldicarb and Neem seed powder in the management of root knot nematode (*Meloidogyne incognita*) infesting okra (*Abelmuschus esculentus* L. Moench) in Maiduguri (Sudan Savanna) and Geidam (Sahel Savanna), North East Nigeria

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Abstract
An experiment was conducted in Maiduguri; sudan savanna and Geidam; sahel savanna zones of Nigeria to compare the efficacy of neem seed powder (NSP) with the synthetic nematicide aldicarb in the management of the root knot nematode *Meloidogyne incognita* infesting okra. The experiment was laid out in completely randomize block (CRB) design with four treatments replicated three times. In each block the okra variety ladyfinger was assigned to the main plots while neem (1ton/ha) alone, Aldicarb (2kg ai/ha 3G) alone, neem and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G) and untreated-control were assigned to the subplot. Each experimental plot was amended with the treatments according to the experimental design. Data were recorded on initial and final nematodes population, plant height, number of leaves, fresh shoot weight, dry shoot weight and Galling index. The results revealed significant effect of aldicarb and NSP and aldicarb in combination on final nematodes population over the untreated controls and NSP alone. No significant difference was observed among the treatments in terms of plant height and fresh shoot weight. However, in both locations all the treatments recorded significantly higher number of leaves, higher weights of dry shoots over the untreated controls. Significantly lower galling indexes were recorded in all the treatments over the untreated control in both locations.

Keywords: *Abelmuschus esculentus*, Aldicarb, Meloidogyne incognita, NSP, RKN

Introduction
Okra, *Abelmoschus esculentus* (L) Moench originated from Abyssinia which in the modern world includes the present Ethiopia, higher parts of Anglo-Egyptian Sudan a nd some portion of Eritrea. Okra is widely acceptable fruit vegetable throughout the world due to its food value. Okra is use as a vegetable; it is also cultivated for its immature pods which contains a gum that makes a slimy and thick mucilage which is used in thickening soups and stews. Okra is one of the most important vegetables in Nigeria. Okra seed contains oligomeric catechins (2.5mg/g of seeds) and flavonol derivatives (3.4mg/g of seeds), while the mesocarp is mainly composed of hydroxycinnamic and quercetin derivatives (0.2 and 0.3mg/g of skins). Pods and seeds are rich in phenolic compounds with important biological properties like quartering derivatives, catechin oligomers and hydroxycinnamic derivatives [1]. These properties, along with the high content of carbohydrates, proteins, glycol-protein, and other dietary elements enhance the importance of this foodstuff in the human diet [1]. It is a warm season crops that is grown in the tropical and subtropical regions of the world [2]. It is among the most heat and drought tolerant vegetable species in the world and will tolerate soils with heavy clay and intermittent moisture but frost can damage the pods. The production of Okra in Nigeria like in many other African countries is constrained by so many problems which results in low production. Among these threats the root knot nematode (RKN) is a major pest of Okra and other vegetables in Nigeria. The RKN *Meliodogyne incognita* (*M. incognita*) have been generally categorized as silent enemies and in some cases losses of up to 80% have been associated with them in vegetable fields that are heavily infested [3]. RKN have been found to be a major threat to the production of sufficient food and fibre crops in Nigeria and many developing countries [4].

Okra is reported to suffer more than 90% yield loss when grown in fields infested with 3 - 4 *M. incognita* per gram of soil [5]. Farmers in most okra producing areas in Nigeria rely on synthetic insecticides to manage the RKN; *M. incognita*. The use of synthetic nematicides is however associated with many problems such as introduction of toxic residues into the food of man and other mammals, it is detrimental to environment, destabilizes the micro-ecosystem by eradicating natural enemies, it leads to the development of resistance by RKN and other pests and increases pest population levels. Therefore, it is very necessary to control *M. incognita* due to its high economic damage to okra crops in a way that neither the environment nor human beings and other mammals are harmed. Toxic substances to RKNs are seen in many plants and plant decomposition [6]. Many plant extracts are effective in suppression of RKNs. These efficacious extracts belonged to 46 plant families including both annuals and perennials [7]. Therefore, it is logical to examine new plants or new varieties of plants for their efficacy in immobilizing, retarding development or killing nematodes. Among the several ecologically-based approaches in nematode management is the use of pesticides of plant origin [8]. Neem, *Azadirachta indica*, is known to possess potential nematicidal compounds. Various neem products, oils, cakes, extracts, powder etc prepared from leaves and seeds are used as seed treatment and root-dips for the control of nematode pests. According to the previous studies Azadirachtin is the major nematotoxic compound in neem and all other nematotoxic compounds are released through volatilization, exudation, leaching and decomposing of the plant parts [9, 10]. This study focusses mainly on the investigation of the effects of NSP and Aldicarb (A synthetic nematicide) as soil amendments in the management of root-knot nematode; *M. incognita* affecting okra plants in Maiduguri (Sudan savanna zone of Nigeria) and Geidam (Sahel savanna zone of Nigeria).

Materials and methods

Experimental location

The experiment was conducted at Farm Center, Maiduguri of Borno state (11º50ˈ48.9ˈˈ N 13º9.427ˈˈ E), Sudan Savanna and Kalgeri, Geidam local government area of Yobe state (12º53ˈ49ˈˈ N 11º55ˈ49ˈˈ E); Sahel Savanna Nigeria during the 2020 raining season. The land was cleared, harrowed by a tractor and leveled manually using a hoe.

Experimental design

The experiment was laid out in completely randomize block design. The okra variety lady finger was used and it was assigned in the main plot while four (4) nematicide treatments: neem (1ton/ha) alone, Aldicarb (2kg ai/ha 3G) alone, neem and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G respectably) and control were assigned to the subplot. Each block has four treatments and each treatment was replicated three times making a total of twelve treatment plots.

Source of materials

The okra cultivar Lady finger was obtained from the market in Maiduguri, while the neem seeds were collected from Geidam and Maiduguri and the nematicide aldicarb was also purchased from Monday market, Maiduguri, Borno State, Nigeria.

Collection and processing of neem seeds

Ten 50Kg bags of neem Seeds were collected from Geidam which was dried under shade before being pounded with a wooden stick to make a coarse powder. Aldicarb was purchased from the market in Maiduguri. Worm Force, which contain Aldicarb 3% G active ingredient. manufactured by Jubaili Agrotec. Production date 28, June 2020 and the expiry date 28, June 2022 was used.

Treatments and their application, sowing and other management operations

Each experimental plot was amended with the treatments according to the experimental design. Neem seed powder (NSP) was applied and thoroughly mixed with the soil up to a depth of about 15-20cm using hoe. The aldicarb was applied three (3) days after emergence by broadcasting in sowing rows with incorporation in the soil for 2-5cm as depth. Three seeds per hole were sown two weeks after application of treatments at the depth of 3cm to 5cm and spacing of 50cm × 50cm. The seedlings were later reduced to two plants per stand two weeks after emergence making a total of 16 plants per plot. There after weeding was done at three weeks after sowing and subsequent weeding was done weekly to minimize weed interference. Missing stands were replaced to maintain the intended plant population at the initial stage.

Nematode investigation

Initial (before application of treatments) and final (after crop harvest) nematode population was determined by taking three core samples with a soil auger at a depth of 20cm in a zig-zag pattern from each experimental plot which were bulked and labeled. Soil samples collected from each plot were analyzed in the laboratory to determine the plant parasitic nematode population. The White-Head and Hemming, (1965) method of nematode extraction was used. The following nematode investigation were carried out.

i. Initial population (Pi) before application of treatment would be determined for each plot.
ii. Final nematode population (Pf) in the soil after harvest.
iii. Reproduction factor (RF): this was determined by dividing the final population (Pf) by the initial population (Pi) that is: RF = Pf /Pi
iv. Change in nematode population

Change in nematode population was determined by calculating the percentage using the formula:

$$\frac{Pf - Pi}{Pi} \times 100$$

Pi = Initial nematode population per 250 cm^3 of soil
Pf = Final nematode population per 250 cm^3 of soil

Recovery and estimation of root-knot nematode from the Soil

The White-Head and Hemming, (1965) method was used in the extraction of nematodes from the soil samples. Two layers of tissue paper were placed in a netted plastic basket which was spread thinly over the surface of the plastic tray, the root-knot infested soil was spread thinly over the surface of the tissue paper. Water was poured gently into plastic tray until

the soil sample becomes moist, caution was taken not to be over saturated. Trays with moist soil sample were left over for 24 hours. Active stage of the nematodes swims from the moist soil slowly down through the tissue paper into the tray containing water and settled at the bottom. Suspension with nematodes were collected into 200mls beaker and the nematodes were allowed to settle for a couple of hours. The excess water in the beaker were poured off leaving relatively about 50mls suspension nematodes. Three (3) aliquots of 5ml each were pipette out from the suspension after agitation and suspension were poured into 3 counting dish separately. The nematodes were counted in each dish under microscope and the average of 3 would be calculated.

Identification of nematode genera

Nematode identification was done under a compound microscope by picking with a broomstick target nematode from the counting dish and placed under the stereomicroscope, and transferring to glass slide covered with a slip and observed under the appropriate magnification of the compound microscope. Identification of the different nematode genera were done using nematode key of Dropkin (1980) and using crop protection compendium (edition 2004) and also key to a few group of plant parasitic nematodes used by permission of national association of biology teachers.

Observation and measurement of plant parameters

Five plants per plot were randomly selected for determination of growth and yield parameters. The parameters measured include plant height (cm), number of leaves, fresh shoot weight (g) and dry shoot weight (g).

Plant height (cm)

Plant height (cm) of each of the five plants selected randomly were measured from the soil surface up to the top of the plant using measuring tape and average height recorded.

Number of leaves

The total number of leaves of each of the five plants selected randomly were physically counted and the average number of leaves were recorded.

Fresh shoot weight (g)

Sensitive electronic weighing balance was used to measure the shoot of the five plants selected randomly and the average weight (g) was recorded.

Dry shoot weight (g)

Dry shoot weight (g) would be measured and recorded using sensitive electronic weighing balance.

Galling index

To assess the extent of galling on the roots in each treatment and control, five samples from each plot were selected randomly and carefully uprooted at the end of the experiment. The root was washed in clean water and dirt was removed. The root was examined using hand lens, the number of the galls was counted and indexed according to the indexing scale of Ibrahim and Lewis, (1985).

0	1-2 galls	(completely resistance)
1	3-10 galls	(moderately resistance)
2	11-30 galls	(slightly resistance)
4	31-100 galls	(slightly resistance)
5	more than 100	(susceptible)

Data analysis

All the data obtained were subjected to statistical analysis appropriate to completely randomize block (CRB) design analysis of variance (ANOVA). Difference between means were determined using the least significant difference (LSD) Statistic at ($P \leq 0.05$).

Results and discussion

The results obtained from this study has clearly shown the occurrence and incidence of root-knot nematodes in the two study locations; Maiduguri (Sudan savanna) and Geidam (Sahel savanna) zones of Nigeria. In both locations, the root knot nematodes *M. incognita* were found infesting okra.

Table 1 and 2 shows results on the effect of neem seed powder (NSP) and aldicarb on initial and final nematodes population in Maiduguri (Sudan Savanna) and Geidam (Sahel Savanna) both in Nigeria. The data obtained generally showed that higher final nematodes population were recorded in the untreated controls (159.67^a) and NSP at 1 ton/ ha (154.88^a) in Maiduguri. Similarly, in Geidam the highest final nematodes population were recorded in the untreated controls (158.33^a) and NSP at 1 ton/ha (156.67^a) respectively. Significantly, lower number of final nematodes population were recorded in the aldicarb (Nematicides) treated plots (136.33^b) and neem and Aldicarb in combination (136.00^b) in Maiduguri. Similarly, lower number of final nematodes population were recorded in the aldicarb treated plots (128.33^b) and NSP and aldicarb in combination (130.00^b) respectively in Geidam. In this study significant effect of Aldicarb and NSP were observed in reducing *M. incognita* in the soil. This study is in agreement with the work of Yasmin *et al*., (2003) [11] who found that extract of neem seed was more effective against final population of the nematode *M. javanica*. Also, (Chitwood, 2002) [12] reported that numerous plants species produce allelochemicals with antagonistic effect towards certain populations of plant-parasitic nematodes such as *M. incognita* and neem derivatives are one of these plants. Similarly, Gombo (1998) [13] in his experiment showed that degradation of neem leaves on the incidence of root knot nematodes have shown significant effect in reducing the number of *M. incognita* population in the soil drastically.

Table 3 and 4 shows data on the effect of NSP, Aldicarb, NSP and Aldicarb in combination and control on plant height and number of leaves in Maiduguri and Geidam. In Maiduguri, there was no significant difference among the treatments with regards to plant height even though the highest plant heights were recorded in the Aldicarb treated plots (49.00^a) and the NSP and Aldicarb in combination treated plots (48.00^a) respectively. Similar result was obtained in Geidam in which no significant difference was observed among the treatments although higher plant heights were recorded in the plants whose soils were treated with Aldicarb, (32.20^a) and the NSP and Aldicarb in combination (30.58^a). In Maiduguri, data recorded on the number of leaves showed that significantly higher number of leaves were recorded in plants whose soils were treated with NSP, Aldicarb, NSP and Aldicarb in combination which were 11.70^a, 12.00^a and 11.75^a respectively. The non-treated control recorded the lower number of leaves 9.00^b. Similar result was obtained in Geidam in which the highest number of leaves were recorded in plants whose soils were amended with NSP, Aldicarb, NSP and Aldicarb in combination which were 8.90^a, 10.80^a and 10.50^a respectively, significantly, lower number of leaves were recorded in the untreated controls. This study showed

that Plants treated with aldicarb and NSP in combination with aldicarb gave significantly higher number of leaves than the untreated controls. This is simply because of the inability of the plants in the untreated control to take up adequate amounts of water and nutrients needed for photosynthesis because of the presence of the root knot nematodes, Plants with more root-galls would translocate less nutrients to vegetative organs [14]. This study is in line with the work of Alabama and Alabama (2009) [15] who observed that nematodes damage plants by feeding on the roots weakening the ability of the plants to take up nutrients which leads to stunt growth and fewer leaves for photosynthesis. Here, the synthetic nematicide; aldicarb and the NSP played an important role in suppressing the root knot nematodes in the soil and ensured adequate supply of nutrients and water needed for photosynthesis through the higher number of leaves produced.

Table 5 and 6 presents data on the effects of NSP and aldicarb on fresh shoot weight and dry shoot weight in Maiduguri (Sudan Savanna) and Geidam (Sahel Savanna), Nigeria respectively. Data recorded showed that, in Maiduguri there was no any significant difference among the treatments with respect to the weight of fresh shoots even though slightly higher weights of fresh shoots were recorded in the plants whose soils were amended with the nematicide; aldicarp and those plants whose soils were amended with Aldicarp and NSP in combination (14.30^a and 14.00^a). Similar results were recorded in Geidam in which no significant differences among the treatments were observed in terms of weight of fresh shoots even though slight differences were observed over the untreated control as 16.25^a, 17.50^a, 16.75^a and 16.15^a (Untreated control) respectively. In Maiduguri, all the treatments recorded significantly higher weights of dry shoots weight over the untreated control which were 6.25^a, 6.70^a, 6.25^a and 5.50^b (Untreated control) respectively. Similar results were obtained in Geidam in which Significantly higher dry shoot weights were obtained in all amendments over the untreated controls and the data recorded were 9.50^a, 9.75^a, 9.55^a and 5.25^b (Untreated control) respectively. This work is in conformity with the work of Sale (2004) [16] who finds out from his studies that yield parameters such as dry shoot weight from treated plot were significantly higher than that of untreated control plot. This is simply because nematode multiplies freely and intensifies their activities in the untreated plot while their growth was checked in the treated plots and the resulting high population may lead to yield loss. The nematode and newly formed host tissue serve as a metabolic sink into which the plant divert nutrient that was normally sent to leaves, flowers and fruits. According to previous studies azadirachtin is the major nematotoxic compound in neem and all other nematotoxic compounds are released through volatilization, exudation, leaching and decomposing of the plant parts which also serve as additional nutrient that increases crop yield [9, 10]. Many reports in literature emphasized the role of neem in controlling plant-parasitic nematodes and as organic manure for increasing yield [17].

Table 7 shows result on the effect of NSP, aldicarb, NSP and aldicarp in combination on galling index in Maiduguri and Geidam. Significantly higher galls were recorded in the untreated controls compared to all the treatments used. Maiduguri recorded 48.88^b, 45.00^b. 45.00^b and 50.88^a (Untreated control) galling index with the untreated control recording the highest galling index. While the galling index recorded in Geidam were 63.00^b, 61.75^b, 63.25^b and 68.75^a (Untreated control) with the untreated control recording the highest galling index respectively. This finding is in line with the work of Javed *et al*., (2001) [18] who studied the nematicidal efficacy of nimbokil (neem cake product), algaefol (sea algae extract), a microbial product and mehndi for egg inhibition and root gall index. They found that the neem cake Nimbokil as the most effective.

Table 1: Effect of NSP and Aldicarb on initial and final nematode (*M. incognita*) population recovered from 250cm^3 of soil in Maiduguri

Treatments	IP (Per 250 cm^3)	FP (Per 250 cm^3)
T_1	202.00	154.88^a
T_2	195.66	136.33^b
T_3	190.33	136.00^b
T_4	213.66	159.67^a
LSD		**18.36**

Means followed by the different letter(s) along the column are not statistically different at 5% probability level IP = Initial Population, FP = Final Population, T_1 = NSP (1ton/ha), T_2 = Aldicarb (2kg ai/ha 3G), T_3 = NSP and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G respectably), T_4 = Untreated control and LSD = Least significant difference

Table 2: Effect of NSP and Aldicarb on initial and final nematode population recovered from 250cm^3 of soil in Geidam

Treatments	IP (Per 250 cm^3)	FP (Per 250 cm^3)
T_1	187	155.67^a
T_2	215	128.33^b
T_3	197	130.00^b
T_4	189	158.33^a
LSD		**23.18**

Means followed by the different letter(s) along the column are not statistically different at 5% probability level IP = Initial Population, FP = Final Population, T_1 = NSP (1ton/ha), T_2 = Aldicarb (2kg ai/ha 3G), T_3 = NSP and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G respectably), T_4 = Untreated control and LSD = Least significant difference

Table 3: Effect of NSP and Aldicarb on plant height and number of leaves in Maiduguri

Treatments	Plant Height (cm)	Number of Leaves
T_1	47.78[a]	11.70[a]
T_2	49.00[a]	12.00[a]
T_3	48.00[a]	11.75[a]
T_4	46.42[a]	9.00[b]
LSD	**NS**	**2.55**

Means followed by the different letter(s) along the column are not statistically different at 5% probability level IP = Initial Population, FP = Final Population, T_1 = NSP (1ton/ha), T_2 = Aldicarb (2kg ai/ha 3G), T_3 = NSP and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G respectably), T_4 = Untreated control and LSD = Least significant difference, NS = Non significant

Table 4: Effect of NSP and Aldicarb on plant height and number of leaves in Geidam

Treatments	Plant Height (cm)	Number of Leaves
T_1	30.00[a]	8.90[a]
T_2	32.20[a]	10.80[a]
T_3	30.58[a]	10.50[a]
T_4	29.00[a]	8.30[b]
LSD	**NS**	**2.1**

Means followed by the different letter(s) along the column are not statistically different at 5% probability level IP = Initial Population, FP = Final Population, T_1 = NSP (1ton/ha), T_2 = Aldicarb (2kg ai/ha 3G), T_3 = NSP and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G respectably), T_4 = Untreated control and LSD = Least significant difference, NS = Non significant

Table 5: Effect of NSP and Aldicarb on fresh shoot weight and dry shoot weight in Maiduguri

Treatments	Fresh shoot weight	Dry shoot weight
T_1	13.75[a]	6.25[a]
T_2	14.30[a]	6.70[a]
T_3	14.00[a]	6.25[a]
T_4	13.00[a]	5.50[b]
LSD	**NS**	**0.75**

Means followed by the different letter(s) along the column are not statistically different at 5% probability level IP = Initial Population, FP = Final Population, T_1 = NSP (1ton/ha), T_2 = Aldicarb (2kg ai/ha 3G), T_3 = NSP and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G respectably), T_4 = Untreated control and LSD = Least significant difference, NS = Non significant

Table 6: Effect of NSP and Aldicarb on fresh shoot weight and dry shoot weight in Geidam

Treatments	Fresh shoot weight	Dry shoot weight
T_1	16.25[a]	9.50[a]
T_2	17.50[a]	9.75[a]
T_3	16.75[a]	9.55[a]
T_4	16.15[a]	5.25[b]
LSD	**NS**	**4.20**

Means followed by the different letter(s) along the column are not statistically different at 5% probability level IP = Initial Population, FP = Final Population, T_1 = NSP (1ton/ha), T_2 = Aldicarb (2kg ai/ha 3G), T_3 = NSP and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G respectably), T_4 = Untreated control and LSD = Least significant difference, NS = Non significant

Table 7: Effect of NSP and Aldicarb on Galling index in Maiduguri and Geidam

Treatments	Galling Index (GI)	
	Maiduguri	Geidam
T_1	48.88[b]	63.00[b]
T_2	45.00[b]	61.75[b]
T_3	45.00[b]	63.25[b]
T_4	50.88[a]	68.75[a]
LSD	2.76	5.07

Means followed by the different letter(s) along the column are not statistically different at 5% probability level IP = Initial Population, FP = Final Population, T_1 = NSP (1ton/ha), T_2 = Aldicarb (2kg ai/ha 3G), T_3 = NSP and Aldicarb in combination (0.5ton/ha and 1kg ai/ha 3G respectably), T_4 = Untreated control and LSD = Least significant difference

Conclusion

It can be concluded from this work that NSP is as effective as the synthetic nematicide aldicarb in suppressing the root knot nematode *M. incognita* and in enhancing maximum production of okra. It is therefore recommended for the farmers in the Sudan and Sahel savanna zones of Nigeria to adopt and practice the application of neem seed extracts alone and in combination with reduced concentration of aldicarb in their farms where nematodes have been destructive to okra since neem seed extracts has shown to be effective, cheap and environmentally safe in managing *M. incognita*. Moreover, the use of synthetic nematicides has several disadvantages such as high cost of procurement, development of resistance by pests, introduction of toxic residues into the food of man and other mammals and environmental degradation.

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