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EFFECT OF SOIL TYPE AND SOIL DEPTH ON THE REPRODUCTIVE PERFORMANCE OF TWO SPECIES OF GIANT AFRICAN LAND SNAILS IN THE HUMID TROPICS

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ABSTRACT
Eggs of two species (genotypes) of Giant African land snails – *Archachatina marginata* (genotype 1) and *Achatina fulica* (genotype 2) were evaluated for fertility, hatchability and embryo mortality using three soil types and soil depths. 180 eggs were randomly selected from eggs laid by each genotype and 10 eggs were incubated in each soil depth. Each soil depth was replicated twice giving two hatches per soil depth, 6 hatches per soil type, and 18 hatches per genotype. Results indicate significant differences ($P \leq 0.05$) between genotypes for all parameters evaluated except fertility. Eggs of *A. fulica* hatched better than those of *A. marginata* in all soil types and soil depths. Effects of different soil types on the hatching variables were not significantly different ($P \geq 0.05$) across genotypes. On the contrary, soil depth significantly ($P \leq 0.05$) influenced hatchability and embryo viability across genotypes. Effect of genotype x soil type interaction was not significant for all variables whereas genotype x soil depth, soil type x soil depth and genotype x soil type x soil depth interactions highly significantly ($P < 0.001$) influenced hatching in the two genotypes. From the results obtained, it was concluded that eggs of the two snails can hatch in the three soil types and soil depths evaluated but loamy soil was found the best medium and 3cm the best soil depth to hatch eggs of the two species. Interaction effects revealed (1) that soil depth can be used to ameliorate the shortcomings of an inappropriate soil type (2) that eggs *of A. marginata* are more sensitive to differences in soil type and soil depth and (3) that eggs of *A. fulica* were more tolerant to differences in soil type and changes in soil depth hence they hatched better across soil types and soil depths.

KEYWORDS: Genotype, hatchability, *A. marginata, A. fulica*

INTRODUCTION

Snail farming is a form of micro-livestock production. Micro-livestocks play complementary role in the provision of animal protein to humans. Snails are important sources of animal protein and contain almost all the essential amino acids required by man (Ejidike, 2002). Snail meat is widely consumed all over the world both by the rich and the poor (Murphy, 2001; Ebenso, 2003; and Paoletti, 2005). In most countries, demand outstrips supply (Ejidike, 2002; Ejidike, *et al.*, 2002). Gathering and marketing of snails from the wild provide economic sustenance to rural women in developing countries (Ejidike, 2002; Moyin–Jesu and Kemi, 2008) and snail farming has become a tool for poverty alleviation in such countries (Ebenso, 2006; Morjin–Jesu and Kemi, 2008).
Achatina achatina, *Achatina fulica* and *Archachatina marginata* are among the most common land snails in West African (Ejidike, 2002). *Achatina fulica* and *Archachatina marginata* are, however, regarded as the Giant African land snails (GALS) and assume greatest economic importance (Omole *et al.*, 2006; Wikipedia, 2007; Cobbinah *et al.*, 2008). They are hence the most widely farmed species. The success of these snail species in farms has been the result of the production of fertile eggs and viable hatchlings which are then managed to adult stage. Reproduction in snails is affected by soil type, temperature, humidity, rainfall and nutrition (Ejidike *et al.*, 2002, Ebenso, 2006). In the wild, snails lay copious amounts of eggs during the rainy season when conditions are most suitable for breeding and reproduction. They enter into aestivation during the dry months of the year as a result of adverse climatic variables (high temperature, dryness etc) (Ejidike, 2002; Wikipedia, 2007; Cobbinah *et al.*, 2008). Increase in humidity and soil moisture are therefore the biggest factors which trigger breeding.
Giant African land snails hatch their eggs by depositing them in burrows made in the soil or inside manure heaps, under rocks or roots of trees especially during the rainy months of the year. If conditions are favourable the eggs hatch in 27 – 31 days (Ebenso, 2006). All year round breeding in Giant African land snail is, however, possible under controlled environments (Omole *et al.*, 2006; Cobbinah, *et al.*, 2008). Ebenso (2006) reported that optimum conditions for incubation and hatching of eggs of Giant African land snails are 24^0C to 28^0C and 15g of water per 100g of soil. Snails burrow at least two to five centimeters (2 – 5cm) deep to lay and incubate their eggs (Thompson and Cheney 1996; Cobbinah *et al.*, 2008) and some go deeper depending on species (Wikipeida 2007).
Snail soil tolerance differ. Most land snails including the Giant African land snails prefer soils that are slightly alkaline (Ph range 7.0 – 8.0) (Ejidike, 2002). Loamy soil (Garden soil) is reported to be the best for snail husbandry (Cobbinah *et al.*, 2008). Loose soils with 20% to 40% organic content (Thompson and Cheney, 1996) are, however, reputed to be better than compact soils with tendency to cake (Thompson and Cheney, 1996; Ejidike *et al.*, 2002; Cobbinah *et al.*, 2008). However, no reports exist on the effect of different soil depths on hatchability of eggs of African giant land snails.
The present study was hence undertaken to evaluate the effects of three soil types (Loamy, sandy and clay soils) and three soil depths (3cm, 2cm and 1cm) on some hatching performance variables of eggs of two species

(genotypes) of Giant African land snails (*A. marginata* and *A. fulica*) in the humid tropics in order to make appropriate recommendations to snail farmers.

MATERIALS AND METHODS

Study Site

The experiment was conducted at the snailery unit of the Department of Animal Science, University of Nigeria, Nsukka latitude $05^0$22\`North and longitude $07^0$24\`East. Nsukka has an annual rainfall range of 1567.05mm to 1846.98mm. Natural day length is 12 – 13 hours and mean minimum and maximum daily temperatures are 20.99^0C and 30.33^0C, respectively. Relative humidity ranges from 46.68% to 76.20% (metrological centre, crop science dept, UNN, 2008 Unpublished). Nsukka belongs to the humid tropical rainforest zone of south-eastern Nigeria.

Experimental Snails

One hundred and seventy (170) mature snails ($\geq$ 12 months old) made up of 85 *A. marginata* and 85 *A. fulica* each of mean weight 220g and 290g, respectively, were used for the study. The snails were reared in two wooden boxes measuring 48cm x 48cm x 120cm placed inside the snailery unit. The boxes stood 30cm off the ground. The sides of the boxes were constructed with nylon net to facilitate ventilation while the floor had holes for drainage. The boxes were filled with garden soil up to 8cm height from the floor. The soil was thoroughly mixed before snails were introduced into the boxes.

Management and Feeding

All snails were kept under the same environmental conditions and managed similarly. Daily temperatures ranged from 18^0C to 27^0C. Relative humidity and soil moisture were in the range of 75% to 95% and 75% to 85%, respectively. The snails were fed a combination of formulated ration (24% CP, Table 1) and plant food materials (pawpaw fruits and leaves, cocoyam leaves, sweet potato leaves, carrot trimmings, cabbage leaves, etc.).

TABLE 1: Percentage composition of feed fed to the experimental snails (24% CP**)**

Ingredients	% composition
Maize	31.75
Soyabean meal	9.60
Fish meal	9.60
Groundnut cake	12.80
Vit. Premix	0.50
Bone meal	4.00
Wheat offal	31.75
Total	100.00

Experimental Design:

The study was a 2 x 3 x 3 factorial design in randomized complete block (RBC). That is two (2) genotypes, three (3) soil types and three (3) soil depths, respectively. The statistical model is a linear combination of effects of main factors and their interactions thus:

$$X_{ijk} = \mu + G_i + S_j + D_k + (GS)_{ij} + (GD)_{ik} + (SD)_{jk} + (GSD)_{ijk} + e_{ijk}$$

Where,

X_{ikj} = any individual observation.

μ = common mean

G_i = effect of genotype

S_j = effect of soil type

D_k = effect of soil depth

$(GS)_{ij}$ = interaction effect (genotype x soil type)

$(GD)_{ik}$ = interaction effect (genotype x soil depth)

$(SD)_{jk}$ = interaction effect (soil type x soil depth)

$(GSD)_{ijk}$ = interaction effect (genotype x soil type x soil depth)

e_{ijk} = residual (error term)

Egg Collection and Handling:

The snails started laying eggs after 4 weeks of housing in the boxes. Eggs were collected twice daily (early morning and late evening) for 7 days before incubation. Eggs waiting to be incubated were held at 4 – 7^0C in a refrigerator. A total of 360 eggs were collected from each snail species.

Preparation of Hatchery and Incubation

Plastic baskets measuring 10cm deep and 24cm wide were employed for the hatchery operation. Loamy, sandy and clay soils dried to constant temperature of 60^0C for 48 hours were used as incubation media. The hatchery baskets were filled to 2/3 level with homogenous aliquots of each soil type and each soil type was then moistened with water by sprinkling and mixing. 15 grammes of water per 100 grammes of dry soil was adopted according to the recommendation of Ebenso (2006). Holes of 1cm, 2cm and 3cm deep and wide enough to accommodate 10 snail eggs were made in the different baskets (hatchers). Three hatchers were used per soil type, one for each soil depth making nine hatchers per genotype for one replication. Hatching depths were replicated twice so that 18 hatchings were made for each genotype.

One hundred and eighty (180) eggs were randomly selected from the eggs laid by each snail specie and 10 eggs were incubated per soil depth per replicate. The baskets were then placed under the wooden boxes to shed them from direct sunlight and rain. Thermometers were installed in hatchers to monitor soil temperature throughout the incubation period. Eggs hatched between the 28^{th} and 30^{th} day of incubation.

Data Collection and Analysis

All eggs that did not hatch after the 30^{th} day were collected from each soil type and soil depth for each genotype and opened to determine the ones with dead embryos and those that were not fertile *ab initio*. These were counted and recorded by hatch, soil depth, soil type and genotype. From these the following parameters were calculated for each replicate and genotype:

1. $$\text{Fertility (\%)} = \frac{\text{No. of fertile eggs (w)}}{\text{Total no. of eggs incubated (x)}} \, x \, \frac{100}{1}$$

   Where, w = no. of eggs that hatched + no of dead-in-shell

2. $$\text{Embryo mortality (\%)} = \frac{\text{No. of dead in shell (y)}}{\text{Total no. of fertile eggs (w)}} \, x \, \frac{100}{1}$$

3. Hatchability (%) = $\frac{\text{No. of eggs that hatched (z)}}{\text{Total no. of fertile eggs (w)}} \; x \; \frac{100}{1}$

Data were analysed using the ANOVA option of SPSS (2001) statistical package to derive basic statistics (means ± S.E) and to compare treatment means. Significant means were separated using the Duncan option of SPSS. Comparison between genotypes was done using the independent sample T-test statistic also of SPSS. Interaction effects were tested and compared using the interaction option of multiple comparisons in the General linear model of SPSS.

RESULTS AND DISCUSSION

The effects of the main factors (genotype, soil type and soil depth) on the different hatching performance parameters are presented in Table 2.

TABLE 2: Effect of genotype, soil type and soil depth on hatching performance parameters of African giant land snail (*A. marginata* and *A. fulica*)

Factors	Levels	Hatching Performance Parameters							
		No Hatched	No Unhatched	No fertile	No infertile	No dead in shell	Fertility (%)	Embryo motality (%)	Hatchability (%)
Genotype	1[*1]	5.61±0.58^a	4.39±0.58^a	9.39±0.22	0.61±0.22	3.83±0.61^a	85.84±2.11	40.72±6.10^a	59.83±6.21^a
	2[*2]	7.06±0.38^b	2.94±0.38$_b$	9.17±0.26	0.83±0.26	2.11±0.32^b	91.67±2.59	21.86±3.50^b	76.97±3.44^b
Soil type	Loamy	6.92±0.69	3.08±0.69	NA[*3]	NA	2.67±0.58	NA	28.58±6.27	71.39±6.27
	Sandy	5.92±0.65	4.08±0.65	NA	NA	3.50±0.76	NA	35.72±7.48	64.29±7.48
	Clay	6.17±0.56	3.83±0.56	NA	NA	2.75±0.58	NA	29.56±6.40	69.52±6.26
Soil depth	3cm	8.67±0.26^a	1.33±0.26^a	NA	NA	0.75±0.22^a	NA	8.46±2.44^a	92.32±2.15^a
	2cm	5.67±0.48^b	4.33±0.48^b	NA	NA	3.50±0.53^b	NA	36.61±5.61^b	62.38±5.25^b
	1cm	4.67±0.41^b	5..33±0.41^b	NA	NA	4.67±0.48^b	NA	48.79±4.87^b	50.51±4.50^b

a,b: Mean on the same column with different superscripts are significantly different; P < 0.05
*[1] Genotype 1 = *A. marginata*, *[2] = genotype 2 = *A. fulica*; *[3] NA = Not applicable

Mean values obtained for hatching performance showed that genotype 2 (*A. fulica*) eggs performed significantly (P ≤ 0.05) better than genotype 1 (*A. marginata*) eggs in all the parameters evaluated. *A. fulica* had greater number of hatched eggs, higher hatchability, least number of unhatched eggs and dead–in–shell as well as least percentage embryo mortality. Both genotypes were similar for number of fertile eggs and percentage fertility of all eggs incubated. Different soil types did not cause statistically significant differences in the hatching variables at the 95% confidence level even though the values for loamy soil were numerically higher or better than those of other soil types especially for *A. marginata* eggs. Values obtained for different soil depths indicate that 3cm was best for hatching eggs of the two snail species. Specifically, mean number of eggs hatched was 8.67 ± 0.26 (92.32%) for 3cm soil depth as against 5.67 ± 0.48 (62.38%) for 2cm and 4.67 ± 0.41 (50.51%) for 1cm soil depth. Other parameters followed similar trend.

The significant differences in hatching parameters observed for eggs of the two genotypes are expected. Both species belong to different genera. *A. fulica* belongs to the genus *Achatina* while *A. marginata* belongs to the genus *Archachatina* (Moyin – Jesu and Kemi, 2008). Stricking differences in anatomical, behavioural, reproductive, social and nutritional characteristics are, therefore, expected. Differences in adaptive potentials are also normal. For instance, *A. marginata* even though a smaller specie than *A. fulica* produces larger (bigger) eggs (Raut and Barker, 2002). The smaller and lighter eggs of *A. fulica* probably have better shell quality and hence are more hardy and, therefore, more tolerant to adverse/variable incubation conditions than the bigger and probably more fragile *A. marginata* eggs. As a specie, *A. fulica* is reported to be more hardy and hence able to cope with a range of environmental conditions (Raul and Barker, 2002; Cobbinah *et al.*, 2008; Skelley *et al.*, 2010). Collaborative observations with reptile eggs (Andrews and Sexton, 1981); Avian eggs (Paganelli *et al.*, 1974) and amphibian eggs (Sexton *et al.*, 1964) showed that with greater density of fibrils and a thicker matrix of calcium carbonate, egg shells may provide more resistance to water movement (loss or uptake). These adaptive potentials may be the lot of *A. fulica* eggs hence they hatched better in all soil types and soil depths than *A. marginata* eggs. To the above possibilities must be added the fact that bigger eggs require higher temperatures to hatch. It is therefore possible that the moisture level and temperatures of the different soil types at the different soil depths favoured *A. fulica* eggs more than *A. marginata* eggs and soil temperature and moisture content varies with soil depth.

The lack of significant differences among soil types for the different hatching parameters could be as a result of the controlled conditions under which the experiment was conducted. In the natural setting, sandy soil is known to be very porous and therefore unsuitable for hatching of snail eggs (Thompson and Cheney, 1996; Ejidike *et al.*, 2002; Cobbinah *et al.*, 2008). Sandy soil also heats faster but has poor heat retention capacity (cools fast) hence it is characterized by greater temperature variability which is not good for incubation and hatching of eggs. Clay soil on the other hand is too heavy and compact and has the tendency to cake under low water content and to be water logged with the slightest rain. Snails, therefore, find it difficult to burrow into clay soil to lay and hatch their eggs (Thompson and Cheney, 1996). The use of loosened soils, the shadding of the hatchers from direct heat of the sun and rains as well as the periodic sprinkling of water to maintain the moisture content of the incubation media may have ameliorated these shortcomings and improved the hatching performance of the snail eggs especial *A. fulica* in the soil media. Loamy soil is generally accepted to be most suitable for rearing of snails and for hatching of snail eggs (Ebenso, 2006; Wikipedia, 2007; Cobbinah *et al.*, 2008) due to its good water retention capacity and excellent drainage potentials; moderate looseness of the soil particles, good organic content (20% - 40%) and good temperature buffering ability. The highly significant differences observed in the hatching parameters due to varying soil depth indicate that soil depth is a critical factor in the hatching of snail eggs. Snails burrow at least 2cm to lay and hatch their eggs (Wikipedia, 2007; Cobbinah *et al.;* 2008). Burrow depths, however, range from 2 – 5cm in most species (Cobbinah *et al.;* 2008; Thompson and Cheney, 1996) although a few species such as *H. aspersa* make shallower burrows (1 – 1.5 inches) (Thompson and Cheney, 1996) while others make deeper holes (9 – 10cm) (Cobbinah, *et al.;* 2008). Thus, 3cm depth appeared best in the present study for hatching of eggs of the two genotypes and the shallower the holes the lesser the hatching performance especially for *A. marginata* eggs.

Table 3 presents the effects due to genotype x soil type interaction which did not have significant differences in the hatching variables for each genotype.

TABLE 3: Effect of genotype by soil type interaction on hatching performance variables of African giant land snails

		Soil Type					
Variables	Genotypes	Loam	Sandy	Clay	SEM	P-values	Pooled mean ± S.E
No hatched	1	6.33	5.00	5.50			5.61 ± 0.58^a
	2	7.50	6.83	6.83	0.88	0.374	7.06 ± 0.38^b
No unhatched	1	3.67	5.00	4.50			4.39 ± 0.58^a
	2	2.50	3.17	3.17	0.88	0.374	2.94 ± 0.38^b
Embryo Mortality	1	3.33	4.83	3.33			3.83 ± 0.61^a
	2	2.00	2.17	2.17	0.87	0.193	2.11 ± 0.32^b
Mortality (%)	1	35.00	48.03	39.12			40.72 ± 6.10^a
	2	22.17	23.40	20.00	9.00	0.204	21.86 ± 3.50^b
Hatchability (%)	1	65.00	52.00	62.50			59.83 ± 6.21^a
	2	77.78	76.58	76.53	9.08	0.290	76.97 ± 3.44^b

a,b: Mean on the same column with different superscripts are significantly different; $P < 0.05$
Genotype 1; 2 = *A. marginata; A. fulica,* respectively.

The pooled standard error of means obtained for genotypes across soil types showed that performance values for *A. marginata* eggs were more variable than those of *A. fulica* eggs which were more uniform. *A. marginata* eggs performed numerically better in clay soil than in sandy soil unlike *A. fulica* eggs whose performance in clay and sandy soils were almost the same. The values for *A. fulica* eggs (genotype 2) for all the performance parameters across soil types were, however, numerically better than those of *A. marginata* confirming that *A. fulica* eggs were more tolerant to soil differences. The pooled mean values for the two genotypes for all the performance parameters were hence significantly different with *A. fulica* eggs being superior ($P \leq 0.05$) to those of *A. marginata*.

Table 4 shows significant genotype x soil depth interaction.

TABLE 4: Effect of genotype x soil depth interaction on different hatching performance parameters of African giant land snails

		Soil depth				
Variables	Genotypes	1(3cm)	2 (2cm)	3 (1cm)	SEM	P-values
No hatched	1	8.67^a	4.50^b	3.67^b		
	2	8.67^a	6.83^b	5.67^b	0.43	0.024
No unhatched	1	1.33^a	5.50^b	6.33^b		
	2	1.33^a	3.17^b	4.33^b	0.43	0.033
Embryo Mortality (No)	1	0.67^a	4.83^b	6.00^c		
	2	0.83^a	2.17^b	3.33^c	0.42	0.004
Mortality (%)	1	8.40^a	51.67^b	62.08^c		
	2	8.52^a	21.55^b	35.50^c	4.23	0.002
Hatchability (%)	1	93.17^a	48.33^b	38.00^c		
	2	91.47^a	76.42^b	63.02^c	3.85	0.001

a,b: Mean on the same row with different superscripts are significantly different
$P < 0.05$ Genotype 1; 2 = *A. marginata; A. fulica.*

Generally, the two genotypes hatched best at 3cm soil depth than at 2cm and 1cm depths. Number of unhatched eggs, dead–in–shell and embryo mortality were consequently least for 3cm and highest for 1cm. Again, *A fulica* eggs hatched impressively well at all soil depths (91% at 3cm, 76% at 2cm and 63% at 1cm) compared to 93%, 48% and 38% for 3cm, 2cm and 1cm, respectively, obtained with *A. marginata* eggs. Other hatching performance parameters followed the same trend.

The above results indicate that snail species differ in their requirement and/or preference for depth of burrows for laying and hatching of their eggs. The wide range in the depth of burrows (1 – 10 cm) (Thompson and Cheney, 1996; Cobbinah *et al.,* 2008) may account for this. Given the differential egg sizes of the two snail genotypes considered in the present study it does appear reasonable to infer that they differ in soil depth requirement/preference with *A. marginata* eggs requiring deeper burrows than *A. fulica* eggs. Instances of *A. fulica* gravid snails depositing eggs in depth or covers as shallow as 25mm (0.25) is known (Raut and Barker, 2002). Thus, in addition to the adaptive potentials discussed earlier, it does appear that the incubation conditions employed in the present study differentially favoured *A. fulica* eggs more than *A. marginata* eggs and the differential requirements for soil temperature and moisture may be specifically responsible.

The interaction of soil type x soil depth on the hatching parameters are presented in Table 5.

TABLE 5: Effect of soil type x soil depth interaction on different hatching performance variables of African giant land snails (*A. marginata* and *A. fulica)*

	Genotype	*A. maginata*				*A. fulica*			
		Soil Depth							
Variables	Soil type	3cm	2cm	1cm	SEM	3cm	2cm	1cm	SEM
No hatched	Loamy	9.50^{a}	5.00^{b}	4.50^{b}		9.50^{a}	8.00^{a}	5.00^{b}	
	Sandy	8.50^{a}	3.50^{b}	3.00^{b}		8.00^{a}	6.00^{b}	6.50^{b}	0.60
	Clay	8.00^{a}	5.00^{b}	3.50^{c}	0.76	8.50^{a}	6.50^{b}	5.50^{b}	
No unhatched	Loamy	0.50^{a}	5.00^{b}	5.50^{b}		0.50^{a}	2.00^{b}	5.00^{c}	
	Sandy	1.50^{a}	6.50^{b}	7.00^{b}	0.76	2.00^{a}	4.00^{b}	3.50^{b}	
	Clay	2.00^{a}	5.00^{b}	6.50^{b}		1.50^{a}	3.50^{b}	4.50^{b}	0.60
Embryo Mortality (No)	Loamy	0.50^{a}	4.00^{b}	5.50^{b}		0.50^{a}	2.00^{b}	3.50^{c}	
	Sandy	1.00^{a}	6.50^{b}	7.00^{b}		1.50^{a}	1.50^{a}	3.50^{b}	
	Clay	0.50^{a}	4.00^{b}	5.50^{b}	0.60	0.50^{a}	3.00^{b}	3.00^{b}	0.71
Mortality (%)	Loamy	5.00^{a}	45.00^{b}	55.00^{c}		5.00^{a}	20.00^{b}	41.50^{c}	
	Sandy	9.10^{a}	65.00^{b}	70.00^{b}	6.93	15.55^{a}	19.65^{a}	35.00^{b}	8.30
	Clay	11.1^{a}	45.00^{b}	61.25^{c}		5.00^{a}	25.00^{b}	30.00^{b}	
Hatchability (%)	Loamy	95.0^{a}	55.00^{b}	45.00^{b}		95.00^{a}	80.00^{a}	58.35^{b}	
	Sandy	91.0^{a}	35.00^{b}	30.00^{b}	6.23	84.40^{a}	80.35^{a}	65.00^{b}	6.70
	Clay	93.5^{a}	55.00^{b}	39.00^{c}		95.00^{a}	68.90^{b}	65.70^{b}	

a,b,c: Mean on the same row under the same genotype with different superscripts are significantly different; $P < 0.05$

There were highly significant interaction effects on the parameters evaluated. For the two genotypes, hatchability in all soil types was best at 3cm depth (95% for loamy soil, 91% for sandy soil and 93% for clay soil). Below 3cm depth, hatchability became very poor and embryo motality became very high across all soil types especially for *A. marginata* eggs. Specifically, hatchability were 55% for loamy and clay soils and 35% for sandy soil at 2cm and 45%, 30% and 39% for loamy, sandy and clay soils, respectively, at 1cm depth. *A. fulica* on the contrary had comparatively similar hatchability values at 3cm and 2cm soil depths and equally impressive values at 1cm soil depth across all soil types. For instance, hatchability for *A. fulica* eggs was 95%, 84.40% and 95% for loamy, sandy and clay soils, respectively, at 3cm depth; 80%, 80.35% and 68.90% respectively, for the same soils at 2cm and 58.34%, 65% and 65.70%, respectively, for 1cm soil depth. These observations indicate that soil type x soil depth interaction influenced hatching performance of *A. marginata* eggs more than *A. fulica* eggs. Generally, clay soil became better than sandy soil for hatching of *A. marginata* eggs as the incubation depth decreased. Such regular trend was not observed for *A. fulica* eggs. These observations clearly indicate species inspired genetic differences in incubation conditions for eggs of different snail species. *A. marginata* eggs were hence more variable in hatching performance over soil depth for each soil type than was observed for *A. fulica* eggs. The results also show that soil depth could be used to offset the structural deficiencies of sandy and clay soils. This inference is sequel to the observation that at 3cm soil depth, hatching performance was comparatively high for all soil types. For instance, hatchability for *A. marginata* eggs (genotype 1) were 95%, 91% and 93.50% for loamy, sandy and clay soils, respectively. For *A. fulica,* the values were 95% for loamy and clay soils and 84.40% for sandy soil. Percentage embryo mortality were also least for all soil types at the 3cm soil depths (5%, 9.10% and 11.10% for loamy, sandy and clay soils, respectively) for *A. marginata* eggs and (5%, 15% and 5%, respectively) for the same soil types for *A. fulica* eggs.

Table 6 presents the compound effect of interaction among the three factors – genotype x soil type x soil depth.

CONCLUSION

From the results presented, it is inferred that snail eggs can hatch in the three soil types evaluated but loamy soil was found the best medium for hatching snail eggs. For soil depth, 3cm depth was found to be best for all soil types and genotypes followed by 2cm and appropriate choice of soil depth could ameliorate the structural inadequacies of sandy and clay soils for hatching of snail eggs. Of the three (3) main factors evaluated, genotype and soil depth were found to be the most critical factors that influence hatching performance of snail eggs. *A. fulica* eggs were observed to be more tolerant and hence less sensitive to variable incubation conditions hence they performed relatively better across soil media and depths. Generally, a good mix of garden soil at 3cm incubation depth will give above 90% hatchability of fertile viable eggs for *A. marginata* and *A. fulica* eggs.

TABLE 6: Effect of genotype x soil type x soil depth interaction on some hatching variables in two African giant land snails

Genotype	Soil type	Soil depth	No Hatched	No Unhacted	SEM	Embryo mortality	SEM	Mortality (%)	SEM	Hatchability (%)	SEM
	1	3cm	9.50^{a}	0.50^{a}		0.50^{a}		5.00^{a}		95.50^{a}	
		2cm	5.00^{b}	5.00^{b}	0.69	4.00^{b}	0.66	45.00^{b}	7.65	55.00^{b}	6.47
		1cm	4.50^{b}	5.50^{b}		5.50^{b}		55.00^{c}		45.00^{b}	
		Mean	6.33	3.67		3.33		35.00		65.17	
1	2	3cm	8.50^{a}	1.50^{a}		1.00^{a}		9.10^{a}		91.00^{a}	
		2cm	3.50^{b}	6.50^{b}	0.69	6.50^{b}	0.66	65.00^{b}	7.65	35.00^{b}	6.47
		1cm	3.00^{b}	7.00^{b}		7.00^{b}		70.00^{b}		30.00^{b}	
		Mean	5.00	5.00		4.83		48.03		52.00	
	3	3cm	8.00^{a}	2.00^{a}		0.50^{a}		11.10^{a}		93.50^{a}	
		2cm	5.00^{b}	5.00^{b}	0.69	4.00^{b}	0.66	45.00^{b}		55.00^{b}	
		1cm	3.50^{c}	6.50^{b}		5.50^{b}		61.25^{c}	7.65	39.00^{b}	6.47
		Mean	5.50	4.50		3.33		39.12		68.81	
	1	3cm	9.50^{a}	0.50^{a}		0.50^{a}		5.00^{a}		95.00^{a}	
		2cm	8.00^{a}	2.00^{b}	0.69	2.00^{b}	0.66	20.00^{b}	7.65	80.00^{a}	6.47
		1cm	5.00^{b}	5.00^{c}		3.50^{c}		41.50^{c}		58.35^{b}	
		Mean	7.50	2.50		2.00		22.17		77.78	
2	2	3cm	8.00^{a}	2.00^{a}		1.50^{a}		15.55^{a}		84.40^{a}	
		2cm	6.00^{b}	4.00^{b}	0.69	1.50^{a}	0.66	19.65^{a}	7.65	80.35^{a}	6.47
		1cm	6.50^{b}	3.50^{b}		3.50^{b}		35.00^{b}		65.00^{b}	
		Mean	6.83	3.17		2.17		23.40		36.58	
	3	3cm	8.50^{a}	1.50^{a}		0.50^{a}		5.00^{a}		95.00^{a}	
		2cm	6.50^{b}	3.50^{b}	0.69	3.00^{b}	0.66	25.00^{b}	7.65	68.90^{b}	6.47
		1cm	5.50^{b}	4.50^{b}		3.00^{b}		30.00^{b}		65.70^{b}	
		Mean	6.83	3.17		2.17		20.00		76.53	

*: Mean on the same column with different superscripts are significantly different; $P \leq 0.05$

Highly significant differences ($P < 0.001$) in the hatching parameters were observed favouring the two genotypes for loamy soil at 3cm soil depth more than for other soil types and soil depths and confirming the adaptive superiority of *A. fulica* eggs over *A. marginata* eggs in hatching performance over all soil types and soil depths.

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