International Journal of Plant & Soil Science

34(3): 1-9, 2022; Article no.IJPSS.72551
ISSN: 2320-7035

Speargrass [*Imperata cylindrica* (L.) Raeuschel] Growth in Relation to Season, Rainfall and Temperature Patterns of Southern Agro-ecologies of Nigeria

O. A. Aluko [a*], J. O. Amosun [a], A. O. Adetayo [a] and T. O. Dauda [a]

[a] *Institute of Agricultural Research and Training, Obafemi Awolowo University, Moor Plantation, P. M. B 5029, Ibadan, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2022/v34i330840

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/72551

Original Research Article

Received 20 July 2021
Accepted 22 September 2021
Published 12 February 2022

ABSTRACT

Speargrass posed a major constraint to crop producion in some agroecologies in Nigeria. Hence, the study was conducted to investigate the influence of seasons, rainfall and temperature patterns on speargrass components growth with the view to improve its management. This study was conducted between 2014 and 2016 at Eruwa (7˚32'0˚N, 3˚ 25'0 ˚E, 187m altitude) in Derived savanna (DS) and Kishi (08˚.98'N, 003˚.94'E; 364m altitude) in the southern Guinea savanna (SGS)–northern fringe agroecologies of Nigeria. Twelve months of the year starting from July were randomly assigned to plots in an abandoned speargrass infested farmland, replicated three times and arranged in Randomized Complete Block Design. Monthly temperature, rainfall and speargrass samples (shoot and rhizome) were measured. Results showed that rainfall amount varied across the months in both locations. The highest rainfall was recorded in September (264.20 mm) and hottest month was May, 2016 (28.5^{o}C) in Derived savanna between 2014 and 2016 (Table 1). Kishi had 186 mm rainfall in the wettest months and the hottest months had 28.0 ^{o}C within the specified period of the study (Table 2). Total speargrass total dry weight (STDW) increased with rise in rainfall in both locations. Meanwhile, there were variations in the components (Shoot and rhizome) weight. However, there was decline in speargrass dry matter during the dry months (January to April) in the locations. This might have reflected the effects of moisture deficit. Notwisthanding,

**Corresponding author: E-mail: bunmialuko2010@gmail.com;*

Rhizome:shoot varied at both locations. Derived savanna (Eruwa) had rhizome:shoot >1.00 in five months throughout the study ($^{5}/_{24}$), while southern Guinea savanna (Kishi) had rhizome:shoot >1.00 in eleven months ($^{11}/_{24}$). Speargrass control might be more challenging especially in SGS than DS in the months with higher Rhizome:shoot ratio > 1.00. Derived savanna had more months ($^{19}/_{24}$ months) with lower rhizome:shoot ratio (< 1.00) than SGS ($^{13}/_{24}$ months). This might have resulted from more rainy months and better distribution of rainfall in Derived savanna for speargrass shoot growth and the resultant decrease in rhizome:shoot (< 1.00). This is a clue for better translocation of herbicides for season-long speargrass control.

Keywords: Speargrass; rainfall; temperature; rhizome: shoot ratio; derived savanna and southern Guinea savanna.

1. INTRODUCTION

Speargrass is a difficult-to-control weed [1]. It invades 9 – 97% of farmers' field in West Africa and recurs as a major pest in cultivated areas of the upland and moist savanna and humid rain-forest agroecozones in Nigeria [2,3]. Its marked infestation is evident in 73 countries and has been a major limiting factor in the cultivation of 35 annual and perennial crops [4]. This accounts for between 62 and 90% yield reduction in maize, 28.5% to 52.6% in soybean in the middle belt and southwestern Nigeria [5, 6, 7, 8]. In kenaf, speargrass infestation reduced core and bast fibre yield by 67 and 77% respectively, with about 75 to 91% reduction in seed yield [9]. Generally, speargrass management usually increase the cost of crop production and reduce the revenue generated from crop harvest. This cost will increase or decrease as weed species distribution changes in response to future changes in the climate [10].

Models of global climate predict that mean surface air temperature of the earth will rise by 1.5 - 4.5 ^{0}C in the 21st century, due to the doubling of CO_2 concentrations and the enhanced greenhouse effect [11]. Extreme high-temperature events are anticipated to increase in frequency. Plants, in many parts of the world, are thus likely to experience increasing high-temperature stress. However, the effect of increased temperature would be felt in different regions of the world differently. It could be argued that in sub-tropical and tropical regions, an increase of temperature by a few degrees could lead to an increase in EvapoTranspiration (ET) rates to a point that the growth of some species would suffer, due to moisture deficiency. However, changes in rainfall patterns would offset such species responses, under a changing climate. Temperature is the dominant factor that controls plant growth at high (above 50^{0}N) and mid latitudes (above 45^{0}N). At high altitudes, this is due to the influence of temperature on the length of the growing season. Probably the most significant effect of a future increase in temperature in regions where temperate is the main limiting factor, would be to extend the growing season available for plants. However, the effects of such warming on the length of the growing period will again vary from region to region and from crop to crop.

It is generally accepted that higher atmospheric CO_2 is likely to stimulate the growth of crops, and C_3 plants are the most likely to benefit. The consensus of three decades of research is that a doubling of CO_2 concentrations may cause a 10-50% yield increase in C_3 crops like rice, wheat and soybean (Kimball, 1983, Poorter, 1993), the corresponding yield increase expected in C_4 crops, such as maize, sorghum and sugar cane, is 0-10%. However, much will depend on prevailing growing conditions and adequate supply of water and nutrients. On the other hand, this may influence the endemic status of C_3 weed such as speargrass (*Imperata cylindrica* L.) and consequently crop yield reduction and profitable crop production may be adversely affected. The survival of both crops and weeds depend on the response to climate change. Nevertheless, the overall winners of their competition will be the colonising species, because of their superior adaptations and wide ecological amplitudes (i.e. the limits of environmental conditions within which an organism can live and function).

Although it is not possible to be specific, under climate change, weed management will become more important in the future at every scale, from farmlands to regional landscapes. In order to achieve food security, there is need to review weed management strategies in line with climatic and weed flora dynamics. Control of weeds, pests and diseases are all likely to be more difficult and more expensive. Hence, the study investigated the effects of time, rainfall and temperature patterns on speargrass growth in southern agroecologies of Nigeria to guide the decision in management intervention in speargrass endemic agroecologies.

2. METHODOLOGY

The land was an abandoned speargrass infested field at two agroecozones (Derived savanna - Eruwa, 7˚32'0˚N, 3˚ 25'0 ˚E, 187m altitude and Kishi 08˚.98'N, 003˚.94'E; 364m altitude southern Guinea savanna) between 2014 and 2016. The experimental land was a sandy loam soil, densely covered with speargrass. An area of 71 x 17 m was marked out at each location for the study. The site was divided into twelve experimental plots measuring 5 x 5m with 1m alleyway. Twelve months of the year starting from July was randomly assigned to plots and replicated three time and arranged in Randomized Complete Block Design (RCBD). Monthly samples of speargrass shoot and rhizome biomass were collected from 1 sq.m quadrant per plot. The speargrass shoot was cut at soil level, while the soil was dug to 30 cm depth to collect speargrass rhizomes. The samples were oven-dry at 80 ˚C for 48 hours to determine the dry weight of both rhizome and shoot. Rhizome:shoot ratio was determined from the quotient of the dry weight of monthly harvests of rhizome and shoot. Monthly means of rainfall and temperature were obtained for the period which the samples were collected from Nigeria Meteorology station (NIMET) Ibadan. Data were subjected to analysis of variance (ANOVA), using Statistical Analysis System (SAS) and means were seperated with Duncan's Multiple Range Test (DMRT) at 5% level of probability (P = 0.05).

Fig. 1 shows the marked portions of the map representing the study areas. Irepo LGA is located in the Southern Guinea savanna (SGS) – northern fringe and Ibarapa East LGA is situated in the Derived savanna (DS) agro-ecologies of Oyo State.

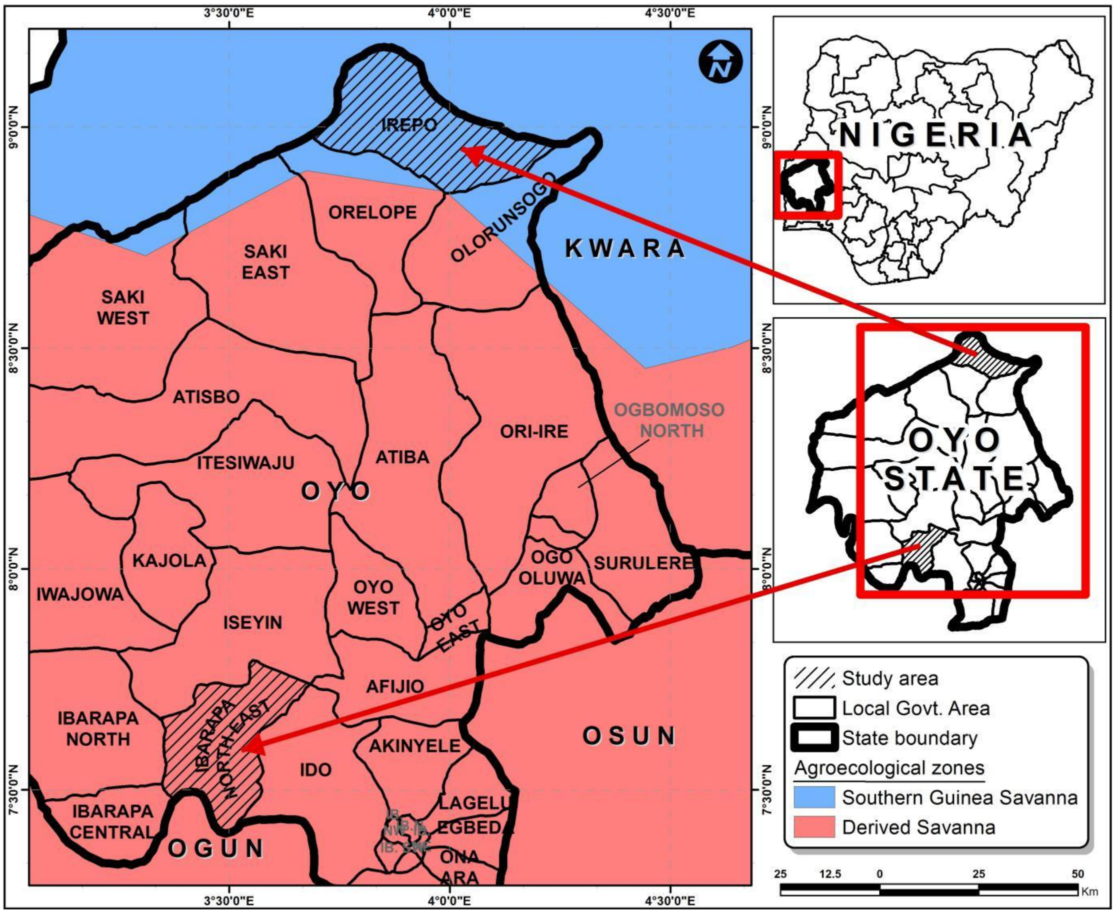

Fig. 1. Map showing the study areas in shaded portions [8]

3. RESULTS

3.1 Effects of Temperature and Rainfall on Speargrass Growth in Derived Savanna and Southern Guinea Savanna

Speargrass growth and components biomass accumulation with time, in relation to rainfall and temperature patterns were significantly different at Derived savanna (Eruwa) between 2014 and 2016. The amount of rainfall varied widely between months. The highest rainfall was recorded in September (264.20 mm), with the lowest and comparable rainfall in November, 2014 to February, 2015. Similar rainfall pattern was recorded in November, 2015 – February, 2016 in Eruwa (DS). Though average ambient temperature readings across the months was highest in February and June, 2016 (28.5 ^{o}C). This was comparable with other months within the study period of two years except september, 2014 and 2015 (25.5 ^{o}C), and December, 2015 (24.5^{o}C) that were comparable at Eruwa (DS). The months with rhizome:shoot ratio ≥ 1.00 (Rhizome:Shoot ≥ 1.00) had more rhizome dry matter than shoot dry matter. On the average, these were three months (February, April and July) in Derived savanna ($^{3}/_{12}$). Where as, months with the mean rhizome:shoot < 1.00 were more durng the specifed period of the study ($^{9}/_{12}$), speargrass had more dry matter accumulated in the shoot than the rhizome (Fig. 2).

Table 2 showed the ranfall and temperature patterns at Kishi (Southern Guinea savanna) within the specified study period. June 2015 had the highest amount of rainfall (192 mm). This was similar to the amount of rainfall in september (2014 & 2015), and June 2016 (184 mm). The highest temperature was 28.0^{o}C within the study period at southern Guinea savanna (Kishi). This was comparable with other months except August, 2014 (25.0^{o}C) that had the minimum temperature.

During the dry months, with amount of rainfall of < 50mm in Kishi (November to April), there was a decline in speargrass dry matter. Speargrass total dry weight increased gradually with increase in speargrass shoot dry weight as a component of the total dry weight. This trend followed an increase in amount of rainfall over the rainy months of May to October. However, southern Guinea savanna (Kishi) had lower number of rainy months and rainfall amount (May – August) and more dry months (September – April) compared with Derived savanna (Eruwa), and lower speargrass component yields and total dry weight were recorded in souther Guinea savanna (Table 2). On the average, four months (January,February, August and September) with rhizome:shoot ratio > 1.00 were recorded in southern guinea savanna (Kishi) during the study (Fig. 3). These months had more rhizome biomass accrual than others (Fig. 3).

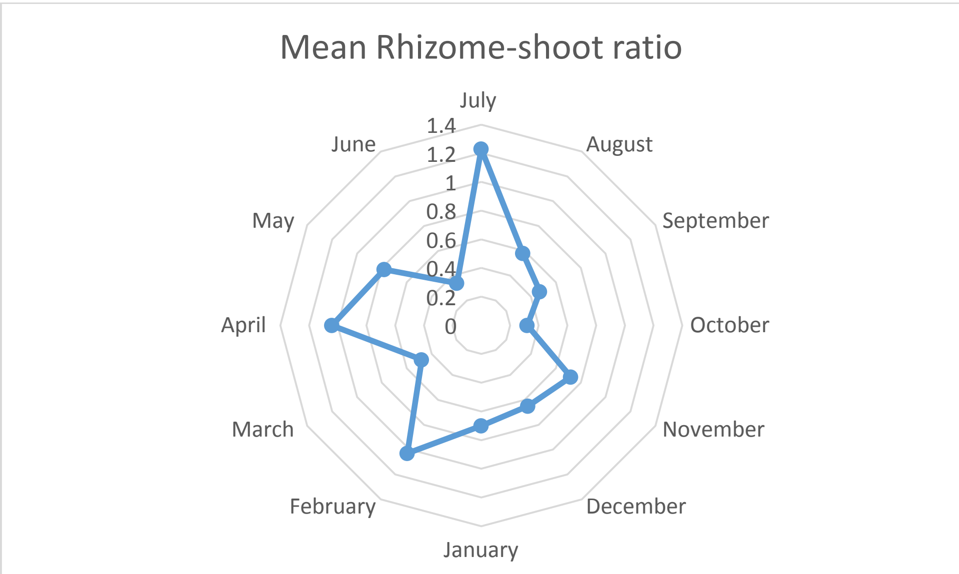

Fig. 2. Mean rhizome-shoot ratio in Derived savanna (Eruwa 2014-2016)

Table 1. Effects of Rainfall and Teperature on speargrass dry matter in Derived savanna agroecology (Eruwa)

Year	Months (24)	Rainfall (mm)	Temperature (°C)	Shoot dry weight (g)	Rhizome dry weight (g)	Total dry weight (g)	Rhizome:Shoot ratio
2014	July	168.8c	26.5ab	116.30ef	135.75c	252.05	1.17
2014	August	124.4de	26.0ab	201.10cd	113.13cd	314.23d	0.56
2014	September	264.2a	25.5b	262.40c	128.92cd	391.32cd	0.49
2014	October	204.3b	26.5ab	329.10b	107.04cd	436.14c	0.33
2014	November	26.3g	26.5ab	107.10e	81.93de	189.03g	0.76
2014	December	0g	27.5a	229.50c	134.73cd	364.23d	0.58
2015	January	2g	27.0a	204.10cd	158.08c	362.18d	0.77
2015	February	16g	27.5a	213.20cd	215.79ab	428.99c	1.01
2015	March	57f	28.0a	186.00d	102.47cd	288.47de	0.55
2015	April	139d	27.5a	112.50de	87.96de	200.46fg	0.78
2015	May	156c	27.5a	117.80de	95.17cd	212.97f	0.81
2015	June	182b	26.0ab	180.03cd	72.80de	252.83ef	0.40
2015	July	173bc	26.0ab	136.30de	175.75bc	312.10d	1.29
2015	August	115de	26.0ab	206.10cd	123.13cd	329.30d	0.59
2015	September	192b	25.5b	362.40b	158.92c	521.3b	0.44
2015	October	29.0fg	26.5ab	539.10a	167.04bc	706.1a	0.31
2015	November	5.0g	26.5ab	87.10ef	58.93e	146.1g	0.68
2015	December	2.0g	24.5b	219.50cd	154.73bc	374.3cd	0.71
2016	January	0g	27.0a	238.90c	148.08cd	387cd	0.62
2016	February	8g	28.5a	253.20c	265.79a	519b	1.05
2016	March	48f	28.0a	236.00c	97.47de	333.50d	0.41
2016	April	107e	28.0a	62.50f	80.96de	143.40g	1.30
2016	May	149c	28.5a	124.80de	93.17de	217.90f	0.75
2016	June	178bc	27.0a	203.30cd	57.80e	261.10ef	0.28

Means with the same alphabet(s) are similar within the specified duration of the study (2014 to 2016) at P=0.05

Table 2. Effects of Temperature and rainfall amount on speargrass dry matter at southern Guinea savanna (Kishi)

Year	Months (24)	Rainfall (cm)	Temperature (^{o}C)	Shoot Dry Weight (g)	Rhizome Dry Weight (g)	Total Dry Weight (g)	Rhizome:shoot ratio
2014	July	166b	26ab	310.25a	103.27b	413.52ab	0.33
2014	August	144c	25b	60.66cd	143.74ab	204.40d	2.40
2014	September	186a	25.5a	49.86d	150.85ab	200.71d	3.03
2014	October	79e	26.5a	119.90bc	129.7ab	249.60cd	1.08
2014	November	9g	27.5a	79.54cd	97.69b	177.23de	1.23
2014	December	2g	28a	128.51bc	162.39ab	290.90c	1.26
2015	January	0g	27.5a	62.22cd	206.42a	268.64cd	3.32
2015	February	0g	27.5a	88.64cd	137.26ab	225.90cd	1.55
2015	March	5g	28a	89.92cd	86.56b	176.48de	0.96
2015	April	45f	26ab	123.18c	101.72b	224.90cd	0.83
2015	May	109d	27a	203.06b	139.17ab	342.23bc	0.69
2015	June	192a	25.5b	166.8bc	124.60ab	291.40c	0.75
2015	July	166b	26.5a	410.25a	73.27ab	483.50a	0.18
2015	August	142c	26.5a	70.67c	193.94ab	204.6de	2.74
2015	September	186a	26a	39.86d	135.86ab	175.70de	3.41
2015	October	82e	26.5a	129.92bc	109.7ab	239.6de	0.84
2015	November	2g	27.5a	99.54bc	70.79ab	170.30de	0.71
2015	December	1g	27.5a	98.61bc	64.39ab	163.00e	0.65
2016	January	0g	28a	73.72bc	226.42a	305.10bc	3.07
2016	February	0g	28a	73.64bc	147.28ab	220.90cd	2.00
2016	March	0g	28a	119.9bc	96.56ab	216.50cd	0.81
2016	April	34f	27.5a	113.18bc	91.75ab	204.90de	0.81
2016	May	121d	27a	213.06b	169.19ab	382.20bc	0.79
2016	June	186a	26.5a	160.8bc	34.64b	194.4de	0.22

Means with the same alphabet(s) are similar within the specified duration of the study (2014 to 2016) at p=0.05

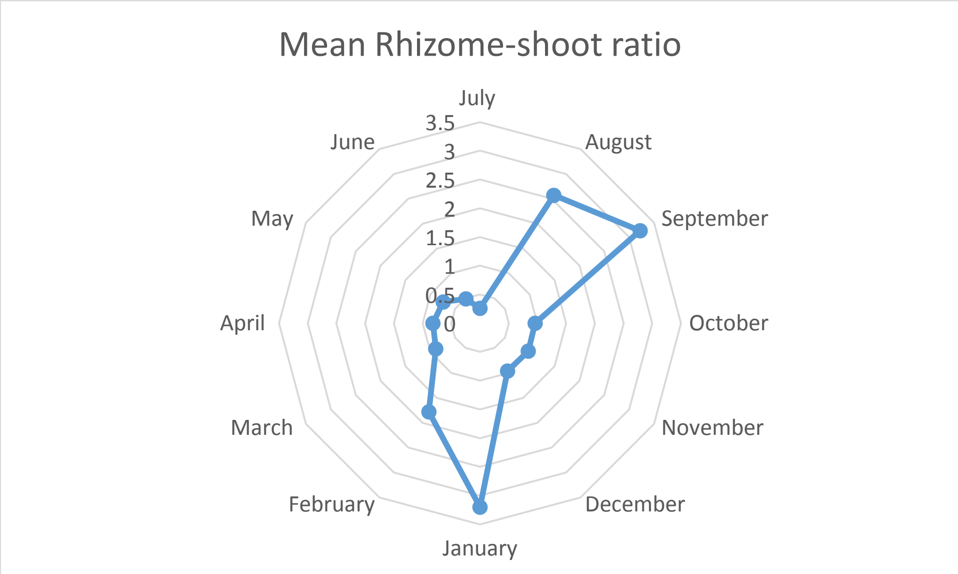

Fig. 3. Mean rhizome-shoot ratio in southern Guinea savanna (Kishi 2014-2016)

Fig. 2 shows the average rhizome:shoot across the sampling dates. Rhizome:shoot > 1.00 was recorded in the months of February, April and July (3months). Whereas, other nine months had Rhizome:shoot < 1.00.

On the average there were five months with rhizome:shoot > 1.00 in southern Guinea savanna (Kishi). These are January, February, August, September and November. Other months had rhizome:shoot < 1.00.

4. DISCUSSION

The amount of rainfall varied widely between months. The highest rainfall was recorded in September (264.20 mm), with the lowest and comparable amount in November, 2014 to February, 2015. Similar rainfall pattern was recorded in November, 2015 – February, 2016 in southern Guinea savanna during the dry season (Table 2). Though average ambient temperature readings across the months was highest in February and June, 2016 (28.5 ^{o}C). This was comparable with other months within the study period of two years except september, 2014 and 2015 (25.5 ^{o}C), and December, 2015 (24.5 ^{o}C) that were comparable at Derived savanna (Eruwa). These variations in both rainfall amount and distribution, and slight changes in temperature were peculiar to the agroecologies. This might have influenced speargrass growth, component biomass as responses to these factors in the agroecologies. Thus, significant increase in speargrass total dry weight (STDW - 413.52 g/m^{-2}) with an increase in rainfall in July 2014 and 2015 at 26.0 ^{o}C and 26.5 ^{o}C of temperature respectively in southern Guinea savanna (Kishi) might have followed the pattern of rainfall. Speargrass had significantly high shoot growth (310.25 g/m^{-2}) in July, 2015. Evidently, speargrass significant physiological response to nutriets available for vegetative growth and biomass accumulation in 2014 and 2015 in southern Guinea savanna. According to Patterson, (1995), the invasiveness of weeds like Itchgrass (*Rottboellia cochinchinensis*) in the same grass family with speargrass may increase with 3^{o}C rise in temperature. This may not be totally ruled out in this study as ambient monthly temperatures increased slightly as the rains became scanty (October – March) at both agroecologies.

Notwithstanding, speargrass biomass was sustained with significantly higher rhizome dry matter which was over two times of the shoot dry weight, indicating the response of speargrass root system to nutrients and moisture stress especially. This annual fluctuations in dry matter accumulation and rainfall resulted from dry spell and wet seasons might also be implicated in speargrass growth, component yield, persistence and subsequent invasiveness earlier reported in these agroecologies [9]. This is in line with the findings of Ladislav (2019), that growth rates of roots and shoots during vegetation period continually adjust to environmental conditions and “genetic program” of plant growth and development. This physiological adjustment of speargrass plant to seasonal rainfall and temperature changes subsequently reflected in the rhizome-shoot ratio across the sampling dates and agroecologies investigated. Lower rhizome:shoot ratio (< 1.00) in better number of months ($^{19}/_{24}$) in Derived savanna (Eruwa), compare to higher rhizome-shoot ratio (> 1.00) in the remaining five months ($^{5}/_{24}$) of the study was an expression of speargrass plant response to fluctuating growth factors in Derived savanna agroecology. However, in southern Guinea savanna (Kishi) with prolonged dry months, rhizome-shoot ratio > 1.00 was more reflecting probably response to moisture stress and other growth factors. Lower rhizome-shoot ratio (< 1.00) in Derived savanna (Eruwa) recorded in higher number of months evidently showed higher speargrass shoot density for vegetative growth. This supports the earlier report by Aluko et al. [9] that there was denser speargrass population in farmers' field in Derived savanna (DS) compared to southern Guinea savanna (SGS) agroecology. However, there were more months with rhizome-shoot ratio > 1.00 in southern Guinea savanna. Thus, speargrass plants with a higher proportion of rhizome can compete more effectively for soil nutrients and withstand stress (drought conditions, low level of nutrients in the soil) than while those with a higher proportion of shoots. This gives better support to the plant for overseasoning during the longer dry period in this agroecology. Speargrass invasiveness may be more pronounced where other competing annual weeds are adversely affected by the dry spell with little or no rainfall (0 - 50mm rainfall).

A critical look at the speargrass growth pattern in relation to rhizome-shoot ratio might give an insight into its vulnerable growth phase for management intervention. In August 2014 and 2015, there was reduction in total dry matter accumulation. However, a shift in accumulated dry matter skewed towards the rhizome. According to Ziska et al. [12], an increase in the root-shoot ratio may play a critical role in herbicide efficacy. Thus, vigorous root growth at the expense of shoot may reduce herbicide efficacy due to poor translocation of herbicide. Dense speargrass rhizome may provide a succour to the plant through its buffer effect from the food reserve in the underground portion. Notwithstanding, lower rhizome-shoot ratio in other months at both locations may provide large surface area for herbicide contact and translocation. Furthermore, uptake of herbicides is reduced with a rise in ambient temperature as weeds develop resistance that prevent translocation of herbicides [13, 14, 15]. This gives further insight into the time of application of such herbicides. The distribution of rainfall may be erratic and less predictable in the future; spread and prevalence of problematic weed such as speargrass may remain endemic as speculated by Peters and Gerowitt [16]. This might also influence the crop-weeds interaction as abrupt changes in climatic variables (rainfall and temperature) among others, may result in stressed crop plants which may be vulnerable to insect pest and pathogens [17], and less competitive against weeds [18]. These subtle changes in weather elements may call for future development and adjustments in crop production technologies, management practices and legislation as speculated by Bhat and Jan [19]. This will inform the method(s) and timing of weed management intervention at different agro-ecologies to enhance season-long speargrass suppression and management of other noxious weeds.

5. CONCLUSION

Rainfall patterns varied across agroecologies investigated. This influenced the growth and components yield of speargrass in these locations. Speargrass growth and rhizome-shoot ratio in the months specified (dry or rainy) were significantly different in response fluctuations in growth factors and location. Rhizome-shoot ratio > 1.00 showed the health and propagule bank and food reserve for speargrass to withstand stress and overseason. Thus, speargrass may be difficult to suppress, unlike rhizome-shoot ratio < 1.00. Southern Guinea savanna had more months with rhizome-shoot ratio > 1.00 than Derived savanna agroecology. Whereas Derived savanna had more months with rhizome-shoot ratio < 1.00 than south Guinea savanna. Identifying vulnerable speargrass growth phase for appropriate management intervention may provide a season-long speargrass suppression and give succour to resource poor farmers in endemic agroecologies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Holm LG, Pucknett DL, Pancho JB, Herberger JP. The World's worst weeds.

Distribution and biology. University Press of Hawaii, Honolulu, HI. 1977;609.
2. Smith MAK. Effects of sampling time and location on growth and development of speargrass, *Imperata cylindrica* (L.) Raeuschel. Applied Tropical Agriculture. 1997;2(2):131-138. In Ibe, A.E. And Madukwe, D.K.: Evaluation of sampling time and location on growth and development of speargrass, *Imperata cylindrica* (L.) Raecuschel in the tropical soils of southeastern Nigeria; 2011.
3. Chikoye D, Ekeleme F, Ambe JT. Survey of distribution and farmers' perceptions of speargrass [*Imperata cylindrica* (L.) Raeuschel] in cassava-based systems in West Africa. International Journal of Pest Management. 1999;45:305-311.
4. Brook RM. Review of literature on *Imperata cylindrica* (L.) Raueschel with particular reference to southeast Asia. Tropical Pest Management. 1989;35:12-25.
5. Koch W, Grobmann F, Weber A, Lutzeyer HJ, Akobundu IO. Weeds as components of maize/cassava cropping systems. 1990;283-298.
6. Udensi UE, Akobundu IO, Ayeni AO, Chikoye D. Management of cogongrass (*Imperata cylindrica*) with velvetbean (*Mucuna pruriens* var. *utilis*) and herbicides. Weed Technology. 1999;13:201-8.
7. Avav T. Control of speargrass (*Imperata cylindrica* (L) Raeuschel) with glyphosate and fluazifop-butyl for soybean (*Glycine max* (L) Merr) production in Savanna zone of Nigeria. Journal of Science, Food and Agriculture. 2000;80:193-196.
8. Aluko OA, Chikoye D, Smith MAK. Effects of tillage, plant spacing and soybean genotypes on speargrass (*Imperata cylindrica* (L.) Reauschel suppression. African Journal of Agricultural Research. 2012;7(7):1068 – 1072.
9. Aluko OA. Speargrass [*Imperata cylindrica* (L.) Raeuschel] dynamics and influence of tillage, spacing and kenaf (*Hibiscus cannabinus* L.) genotypes on its management in Oyo state, Nigeria. (Ph.D Thesis) FUTA, Nigeria; 2018.
10. Hilbert DW, Hughes L, Johnson J, Lough JM, Low T, Pearson RG, Sutherst RW, Whittaker S. Biodiversity Conservation Research in a changing climate. Commonwealth of Australia. Canberra; 2007.
11. IPCC. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, (Eds.) J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, C. A. Johnson, Cambridge University Press, Cambridge. 2001;881.
12. Ziska LH, Faulkner SS, Lydon J. Changes in biomass and root: shoot ratio of field-grown Canada thistle (*Cirsium arvense*), a noxious, invasive weed, with elevated CO_2 : implication for control with glyphosate. Weed Sci. 2004;52:584 – 588.
13. Bailey SW. Climate change and decreasing herbicide persistence. Pest Management Science. 2004;60:158 – 162.
14. Chandresena N. How will weed management change under climate change? Some perspectives. J. Crop Weed. 2009;5:95 – 109.
15. Rodenburg Meinke H, Johnson DE. Challenges for weed management in African rice systems in a changing climate. Journal of Agricultural Science. 2011;149:427 – 435.
16. Peters K, Gerowitt B. Important maize weeds, profit in growth and reproduction from climate change conditions represented by higher temperatures and reduced humidity. Journal of Applied Botany and Food Quality. 2014;87:234 – 242.
17. Reddy PP. Impact of climate change on insect pests, pathogens and nematodes. Pest. Management and Horticultural Ecosystem. 2013;19: 225 – 233.
18. Patterson DT. Weed in a changing climate. Weed Science. 1995;43:685 – 701.
19. Bhat NH, Jan S. Impact of climate change on crop productivity: need of adjustment in agriculture. Research Journal of Agricultural Science. 2010;1:0483 – 486.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/72551