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Fertilizers, Mycorrhizal Inoculation and Atrazine Interactions on Weed Biomass and Yield of Maize

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Abstract

The decline in soil fertility and poor weed management are the dominant limitation on the production of maize in Nigeria. Improving the efficiency of fertilizers through AMF inoculation and atrazine application may be a sustainable way to increase land productivity. Using completely randomised design with three replications, combinations of Organomineral Fertilizer (OF) at 0, 50, 100, 150 kg N/ha^{-} and NPK 15-15-15 (400 kg/ha); Arbuscular Mycorrhizal Fungi (AMF, with and without); and atrazine (0, 1.5 kg a.i/ha) were evaluated in 30 kg pot experiment. Maize grain yield ranged from 0.07-101.20 g/plant. Sole applications of OF, AMF and atrazine increased maize growth and yield. Combining atrazine with AMF inoculation improved maize growth but significantly reduced grain yield (37.13 g/plant) compared to sole applications of AMF (75.13 g/plant) or atrazine (62.97 g/plant). The application of OF did not alter the AMF-atrazine interaction, except under NPK fertilizer application, where the interaction enhanced grain yield. All treatments involving atrazine produced lower total dry weed biomass. However, the total dry weed biomass produced across fertilizer applications increased non-significantly with AMF inoculation, while AMF colonization reduced with atrazine application. Therefore, combining 100 kg N/ha OF with AMF inoculation or atrazine was suggested under organomineral fertilizer application.

Keywords: Organomineral fertilizer, Arbuscular mycorrhizal fungi, Atrazine, grain yield, Dry weed biomass

Introduction

Nigeria has 20.6 million people in 2020 with an annual growth rate of 2.58% (Worldometers, 2020), produced 11.55 million tons of maize (FAOSTAT, 2018). The average estimated yield in 2014 was 2 tons per hectare which is just between 30 – 50% of expected yield. This is majorly attributable to decline in soil fertility (Sileshi et al., 2010). Despite smallholder's adoption of the high-yielding maize genotypes, national per-hectare yield of 1593.3 kg/ha for 2017 in maize productivity is not encouraging. Presently, the challenge of sustaining and improving maize productivity have increased the need to combine improved genotypes with management practices (Ibitola et al., 2019).

Application of inorganic fertilizers are too expensive and not profitable for smallholders (Sileshi et al., 2010). Blanket fertilizer recommendations which ignored the soil and climatic variations have made it unattractive to smallholder farmers (Ibitola et al., 2019). In view of the challenges with fertilizers, arbuscular mycorrhizas (AM) are attracting interest to promote more efficient use of soil mineral resources (Perez-Montano et al., 2014). The contributions of AMF to plant growth with species variation through enhanced nutrients absorption have made it essential components of sustainable crop production (Wenke, 2008; Fitter et al., 2011). Factors such as mycorrhizal diversity/density, soil type, nutrient status, crop and management including herbicide (atrazine) application affect mycorrhizal dependency (Karagiannidis and Hadjisavva-Zinoviadi, 1998; Vatovec et al., 2005; Swanton et al., 2007). For instance, application of atrazine (a selective pre- or post- emergence herbicide applied for the control of weeds in maize) is known to

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influence the populations of certain microbes and crop performance (Ros et al., 2006; Williams et al., 2010). However, the application of organic matter to the soil may modify the effect of atrazine as they adsorb and alter the efficacy of the herbicide (Takeshita et al., 2019). Lack of proper understanding of the interactions among these inputs for enhanced However, the application of organic matter to the soil may modify the effect of atrazine as they adsorb and alter the efficacy of the herbicide (Takeshita et al., 2019). Lack of proper understanding of the interactions among these inputs for enhanced plant benefit require attention. Hence, these studies evaluate the influence of organomineral fertilizer, AM inoculation and atrazine on leaf nutrients concentrations and performance of maize. Also, the effect of these treatments on weed biomass were assessed.

Material and methods

The study site was at Ayepe On-Farm Research (7°17'29.83''N and 4°16'31.88''E) for the Department of Agronomy, University of Ibadan, which was located at Ayepe, Apomu (Isokan LGA), Osun State. Nigeria.

Soil Sampling and Analysis

Composite samples of the topsoil (0 – 15 cm) were collected from the soil gathered from experimental sites before the start of the experiment. The soil samples were bulked and air-dried. The soil samples were passed through a 2 mm mesh sieve for physical and chemical analysis. The soil samples were analysed in the Department of Agronomy service laboratory as described in the IITA laboratory manual (IITA, 1982). Particle size distribution was determined by the hydrometer method as described by Bouyoucos (1951). Soil pH was determined with a glass electrode pH meter (Coleman pH meter) on a 1:1 soil-water ratio. Organic carbon and was determined following the wet oxidation method by Walkey and Black (1934). The nitrogen content of the soil was determined by the Kjeldahl method as adapted by Jackson (1958). The determination of available P in the soil samples was by Bray P-1 method (Bray and Kurtz, 1945). The Ca, Mg, K and Na) were extracted with ammonium acetate ($NH_4C_2H_3O_2$) as described by IITA (1982) and the concentrations determined using flame photometric method for K and Na, while Ca and Mg were determined using Atomic Absorption Spectrophotometer.

The physical and chemical properties of the soil used in the study are shown in Table 1. The soil physical fractions indicated that the soil was loamy Sand in texture. The soil pH was 6.3, while the N, P and K values were 0.78, 5.83 and 0.5 g/kg, respectively. The soil Ca and Mg concentrations were respectively 5.2 and 2.4 cmol/kg.

Table 1. Physical and chemical properties of soils in the experimental location

Parameters	Values
Soil physical fractions (g/kg)	
Sand	844.0
Silt	80.0
Clay	76.0
Soil texture	loamy Sand
Soil chemical properties	
pH (H_2O)	6.3
Exchangeable acidity	0.50
Organic carbon (g/kg)	11.5
N (g/kg)	0.78
P (mg/kg)	5.83
Exchangeable Bases (cmol/kg)	
Ca	5.2
K	0.5
Mg	2.4
Na	0.6
% Base Saturation	56.1
ECEC (cmol/kg)	9.1

Determination of Nutrient Elements in Pacesetter Manure

The Pacesetter Organomineral material was dried at 70 °C for 48 hours and passed through 1 mm sieve in a Willey mill. Total nitrogen was analyzed by wet digestion (micro Kjeldahl method) using a mixture of H_2SO_4 and H_2O_2 (30%) as described by Jackson (1958) and Black (1965). Phosphorus extraction was by Blancher et al. (1965) procedure and the concentration determined in the Technicon Autoanalyzer. Other nutrients determination (Ca, Mg, K) were by using a mixture of HNO_2, HCO_4 and HCl. Potassium concentration was read with a flame photometer while the others were with Atomic Absorption Spectrophotometer.

The values of the chemical properties of the organomineral fertilizer used for this study are presented in Table 2. The N, P and K contents in the organomineral fertilizer were 1.88, 0.23 and 1.01, respectively. The values of Ca and Mg were 0.64 and 0.23, respectively while the organic carbon content was 39.3.

Table 2. Chemical properties of the organomineral fertilizer used for the study

Properties	Organomineral fertilizer
Nitrogen (%)	1.88
Organic carbon (%)	39.3
C: N	20.9
Phosphorus (%)	0.23
Potassium (%)	1.01
Calcium (%)	0.64
Magnesium (%)	0.23

Experimental design

It was a factorial combination experiment in completely randomized design replicated three times. The factors were fertilizers (control, organomineral fertilizer at 50, 100 and 150 kg N ha^{-1} and NPK 15-15-15 at 400 kg/ha as recommended by IITA, 2007); Arbuscular Mycorrhizal Fungi (AMF) inoculation (no AMF inoculation and with AMF inoculation); and pre-emergence herbicide (no atrazine and with atrazine).

Experimental materials

The mycorrhizal fungus used in this study was *Glomus clarum*. It was obtained from the stock kept and maintained in the Soil Microbiology Laboratory of the Department of Agronomy University of Ibadan, Ibadan. The inoculums used consisted of soil containing spores, hyphal fragments, and fine roots of maize infected with G. clarum. Maize (*Zea mays* L.) variety used was open-pollinated yellow Suwan-1, grown by farmers in the locality.

The preemergence herbicide was atrazine applied at 1.5 kg a.i.\ha (ICS-Nigeria, 2011). The organomineral fertilizer was commercially produced (Pacesetter organomineral fertilizer). The NPK 15-15-15 was obtained from the Department of Soil Resources Management, University of Ibadan.

Management

Topsoil (low in phosphorus and nitrogen) was collected from the experimental area at Ayepe. Thirty kilograms of the soil were filled into each pot after sieving with a 2 mm mesh sieve. Each pot was 50 cm in height and 45 cm in diameter.

Organomineral fertilizer was applied at planting, while the inorganic fertilizer was applied at 2 Weeks After Planting (WAP). The fertilizer was applied to maize by ringing around the maize plant. The inoculations in treatments containing AMF consisted of 20 g root placed 1/3 depth of the pot before maize planting (Fagbola et al., 1998). The treatments were arranged randomly in the open field at Ayepe.

Data Collection: Maize: Maize plant height and leaf area were measured fortnightly, from 2-8 WAP. At harvest, shoots dry weight were determined after oven drying the sample at 70 °C to a constant weight. Yield component such as number of kernels/ear, shelling percentage, cob weight/pot, and grain yield/pot (at 14% moisture content) were determined.

Arbuscular mycorrhizal fungal colonization: The colonization of AM fungi was determined using the Giovannetti and Mosse (1980) process. The root samples were cleared for 15 min in 10% KOH at 121 °C and then stained in trypan blue solution. Using a grid-line intersect method, 0.2 g fresh root samples were used in assessing AMF colonization and estimation (Giovannetti and Mosse, 1980).

Weed: Weed biomass (using quadrant) was taken during each weeding operation at 4, 8, and 12 WAP. Afterwards, the frequencies of weeding depended on visual observation. Weeds obtained from the pots were harvested, oven-dried to constant weight for dry weight determination using Binatone weighing balance EK 5055.

Statistical analysis: The collected data were subjected to analysis of variance (ANOVA)and the means compared using Duncan's Multiple Range Test (DMRT) at P < 0.05 level of significance, where F-ratio was significant. Pearson correlation analysis was conducted to determine the relationship between the monitored parameters.

Results

The plant height increased consistently with the plant height increased consistently with increase in plant age in all the treatments (Table 3). The highest plant height at 2 WAP was observed in the treatment involving 100 kg N ha^{-1} OF with AM inoculation and no atrazine application. The lowest plant height was observed in the treatments involving 0 kg N without AM inoculation and no atrazine or with atrazine. The values differed significantly from each other. The treatment involving 100 kg N ha^{-1} with AM and atrazine application gave the highest plant height at 4 WAP, while the treatment with NPK 15-15-15 gave the lowest plant height. However, at 0 kg N, 50 kg N ha^{-1} OF and NPK 15-15- 15 fertilizer treatments, combination involving atrazine excluding AM inoculation gave higher plant height than the other treatment combinations. At 100 and 150 kg N ha^{-1} OF, on the other hand, treatment combination involving AM inoculation with atrazine application gave the highest plant heights. Applying 150 kg N ha^{-1} OF with no AM inoculation or atrazine and NPK 15-15-15 with AM inoculation and atrazine gave significantly higher plant height compared to the control at 6 WAP. Similar trend was observed at 8 WAP, with NPK 15-15-15 combined with AM and atrazine and 150 kg N ha^{-1} OF with no AM or atrazine treatments having significantly higher plant height compared to the control. Within 0 kg N, 50 and 150 kg N ha^{-1} fertilizer treatments at 6 and 8 WAP, treatment with AM inoculation alone gave the highest plant height, while 100 kg N ha^{-1} with atrazine and no AM inoculation gave the highest plant height.

Maize leaf area measured increased with the increase in OF application at 2 WAP with significantly higher leaf area observed in plants treated 100 kg N ha^{-1} combined with atrazine alone compared to many other treatments (Table 4). The highest and significant leaf area at 4 WAP was observed in the maize plants treated with atrazine alone at 0 kg N, while the lowest leaf area was observed in the treatment that had NPK 15-15-15 fertilizer alone. Applying 100 kg N ha^{-1} OF alone significantly increased maize leaf area at 6 WAP compared to plants treated with NPK 15-15-15 fertilizer combined with AM inoculation. At 8 WAP, varying degrees of significance in leaf area measured were observed among the treatments. However, combining AM inoculation with atrazine application at 0 kg N gave the plants with the highest leaf area while the lowest was observed in treatment with 50 kg N ha^{-1} OF combined with AM alone. Across the fertilizer levels including NPK 15-15-15, treatments combining AM inoculation with atrazine application gave the highest leaf area. These treatments were followed by treatments combining atrazine alone across all the fertilizer treatments except at 150 kg N ha^{-1} OF.

Table 3. Response of maize plant height (cm) to the interactions of fertilizers, AM inoculation and atrazine application

Treatments	2 WAP	4 WAP	6 WAP	8 WAP
0 kg N x No AM x No atrazine	4.33c	21.83a-c	44.33c	81.00c
With atrazine	4.33c	22.50a-c	57.00a-c	100.00bc
With AM x No atrazine	6.33ab	22.43a-c	64.00ab	133.67a-c
With atrazine	5.33a-c	22.73a-c	56.33a-c	132.67a-c
50 kg N ha^{-1} OF x No AM x No atrazine	6.33ab	20.60bc	55.00a-c	74.33c
With atrazine	5.33a-c	24.33a-c	63.00a-c	123.00bc
With AM x No atrazine	5.33a-c	21.90a-c	59.00a-c	131.33a-c
With atrazine	5.00a-c	20.00c	55.00a-c	127.67bc
100 kg N ha^{-1} OF x No AM x No atrazine	5.67a-c	25.57ab	62.00a-c	143.00a-c
With atrazine	5.33a-c	25.23ab	68.00a	150.33a-c
With AM x No atrazine	6.67a	23.13a-c	60.33a-c	127.33bc
With atrazine	6.33ab	26.57a	62.00a-c	145.00a-c
150 kg N ha^{-1} OF x No AM x No atrazine	5.33a-c	25.43ab	71.00a	181.33ab
With atrazine	6.00a-c	22.17a-c	60.00a-c	126.67bc
With AM x No atrazine	6.33ab	22.07a-c	56.00a-c	138.00a-c
With atrazine	4.67bc	25.60ab	63.67a-c	132.00a-c
NPK 15-15-15 x No AM x No atrazine	4.67bc	21.00bc	48.00bc	104.00bc
With atrazine	5.33a-c	24.13a-c	65.67ab	155.33a-c
With AM x No atrazine	5.67a-c	23.73a-c	56.33a-c	123.00bc
With atrazine	6.33ab	22.60a-c	72.67a	220.00a
SE	0.66	1.77	6.81	31.61

AM = arbuscular mycorrhizal inoculation; Values within the same column, followed by similar letter(s) are not significantly different at $P < 0.05$ according to Duncan's Multiple Range Test.

Table 4. The interactions of fertilizers, AM inoculation and atrazine application on the leaf area (cm^2) of maize

Treatments	2 WAP	4 WAP	6 WAP	8 WAP
0 kg N x No AM x No atrazine	16.66bc	177.82b-d	289.90 a-c	312.21fg
With atrazine	20.55a-c	251.07a	332.18 a-c	456.82 b-e
With AM x No atrazine	17.95bc	189.83a-d	284.19bc	374.14d-g
With atrazine	25.50ab	187.87a-d	288.16 a-c	631.86a
50 kg N ha^{-1} OF x No AM x No atrazine	18.77bc	154.92b-d	262.29bc	289.79g
With atrazine	14.81c	166.81b-d	245.99bc	407.47c-f
With AM x No atrazine	15.78c	141.22cd	361.73a-c	284.54g
With atrazine	25.65ab	204.05a-c	280.16bc	410.67c-f
100 kg N ha^{-1} OF x No AM x No atrazine	19.25bc	171.64b-d	450.99a	429.81 b-e
With atrazine	28.59a	154.91b-d	264.34bc	459.14 b-e
With AM x No atrazine	20.40a-c	181.16a-d	264.42bc	411.75c-f
With atrazine	17.46bc	189.30a-d	284.27bc	466.39b-e
150 kg N ha^{-1} OF x No AM x No atrazine	19.50a-c	174.27b-d	292.95 a-c	497.36bc
With atrazine	15.66c	181.54a-d	293.60 a-c	448.16 b-e
With AM x No atrazine	17.58bc	154.85b-d	283.54bc	397.00c-g
With atrazine	15.08c	210.62a-c	409.29ab	482.63b-d
NPK 15-15-15 x No AM x No atrazine	15.43c	125.35d	250.64bc	354.43e-g
With atrazine	15.61c	174.06b-d	308.31 a-c	497.69bc
With AM x No atrazine	21.31a-c	204.43a-c	240.41c	425.54b-f
With atrazine	18.72bc	218.15ab	298.76 a-c	541.66ab
SE	3.21	25.21	57.18	40.63

AM = arbuscular mycorrhizal inoculation; Values within the same parameter grouping and column, followed by similar letter(s) are not significantly different at $P < 0.05$ according to Duncan's Multiple Range Test.

The highest and significant dry shoot weight was observed in plants treated with NPK 15-15-15 combined with AM inoculation and atrazine application compared to the lowest observed at 50 kg N ha^{-1} OF without AM inoculation or atrazine (Table 5). At 50 and 150 kg N ha^{-1} OF, combination involving AM inoculation alone gave higher maize dry shoot weight compared to the other treatments within each level. There were varying levels of significance with respect to cob yield differences observed. The maize cob yield varied from 1.60 – 116.27 g plant^{-1} with significantly higher cob yield observed at 100 kg N with AM inoculation alone compared to the control. The 100 kg N ha^{-1} OF combined with AM inoculation alone significantly increased number of kernels per cob observed compared to the control, 50 kg N ha^{-1} OF alone or 50 kg N ha^{-1} OF combined with AM and with or without. All other treatments were not significantly different from the highest value observed. The observed shelling percentages varied in their degree of significance with highest and lowest shelling % observed at 100 kg N combined with AM inoculation alone and the control, respectively. There are varying degrees of significance with respect to grain yield observed. However, the treatment with AM alone at 100 kg N gave the highest grain yield observed, while the control gave the lowest grain yield. Similarly, plants treated with AM inoculation or atrazine at 0 kg N gave significantly higher maize grain yield compared to the control. Furthermore, the application of OF alone above 50 kg N ha^{-1} significantly improved maize grain yield compared to the control. Among the OF levels, combining 100 kg N ha^{-1} OF with AM inoculation alone gave the highest grain yield. The combination involving AM and atrazine lowered maize grain yields across the OF levels. However, NPK 15-15-15 treatment combined with AM and atrazine significantly improved maize grain yield compared to the control.

All the fertilizer treatments combined with atrazine and with/without AM inoculation had significantly lower dry weed biomass compared with other treatment combinations at 4 WAP (Table 6). At 8 WAP, significantly higher dry weed biomass was observed in the treatment combining AM inoculation with atrazine at 0 kg N compared to all sole fertilizer treatments and treatments with AM inoculation alone. The application of 50 kg N ha^{-1} OF combined with AM inoculation alone significantly increased dry weed biomass compared to the control and all treatments without dry weed biomass value at 12 WAP. The total dry weed biomass indicated that there were varying degrees of significance observed among treatments. The total dry weed biomass ranged from 51.06-9.77 g plant^{-1}. The NPK 15-15-15 fertilizer treatment without AM or atrazine gave the highest total dry weed biomass observed, while combining AM inoculation with atrazine at 100 kg N ha^{-1} OF and 150 kg N ha^{-1} OF combined with atrazine alone gave the lowest total dry weed biomass. Across all the fertilizer treatments, combinations involving atrazine significantly reduced total dry weed biomass observed compared to other treatment combinations. However, the combinations of AM inoculation with atrazine further increased total dry weed biomass, except at 100 kg N ha^{-1} OF.

Table 5. Influence of the interactions of fertilizers, AM inoculation and atrazine application yield components and yield of maize

Treatments	Dry shoot (kg plant^{-1})	Cob yield (g plant^{-1})	Shelling %	Grain yield (g plant^{-1})
0 kg N x No AM x No atrazine	0.15cd	1.60f	3.13e	0.07e
With atrazine	0.24a-d	81.90a-e	53.76a-d	62.97a-d
With AM x No atrazine	0.24a-d	104.63a-c	65.33ab	75.13ab
With atrazine	0.23a-d	48.70a-f	69.28ab	37.13b-e
50 kg N ha^{-1} OF x No AM x No atrazine	0.13d	26.90d-f	47.51b-d	22.73b-e
With atrazine	0.22a-d	45.90a-f	65.94ab	36.97b-e
With AM x No atrazine	0.26a-d	10.43ef	28.19c-e	8.97de
With atrazine	0.23a-d	19.93d-f	26.10de	15.60c-e
100 kg N ha^{-1} OF x No AM x No atrazine	0.25a-d	76.80a-e	72.06ab	63.40a-d
With atrazine	0.27a-d	34.83c-f	63.62ab	28.50b-e
With AM x No atrazine	0.35a-c	116.27a	81.09a	101.20a
With atrazine	0.26a-d	45.73a-f	71.10ab	34.50b-e
150 kg N ha^{-1} OF x No AM x No atrazine	0.22a-d	84.87a-d	70.76ab	68.77a-c
With atrazine	0.22a-d	48.50a-f	69.40ab	38.77b-e
With AM x No atrazine	0.38ab	36.17b-f	67.09ab	26.37b-e
With atrazine	0.23a-d	43.20a-f	76.09ab	34.67b-e
NPK 15-15-15 x No AM x No atrazine	0.18b-d	45.73a-f	72.74ab	35.83b-e
With atrazine	0.27a-d	84.53a-d	73.60ab	61.80a-d
With AM x No atrazine	0.21a-d	43.20a-f	59.56a-c	32.23b-e
With atrazine	0.41a	109.03ab	71.22ab	80.23ab
SE	0.08	25.81	11.44	20.60

AM = arbuscular mycorrhizal inoculation; Values within the same column, followed by similar letter(s) are not significantly different at $P < 0.05$ according to Duncan's Multiple Range Test.

Table 6. Dry weed biomass (g plant^{-1}) as influenced by the interactions of fertilizer, AM inoculation and atrazine application

Treatments	4 WAP	8 WAP	12 WAP	Total weed biomass
0 kg N x No AM x No atrazine	31.30ab	0.00c	1.33bc	41.66ab
With atrazine	0.00c	2.10bc	0.00c	13.45d
With AM x No atrazine	28.07ab	0.00c	0.90bc	37.85ab
With atrazine	0.00c	6.93a	0.00c	18.01cd
50 kg N ha^{-1} OF x No AM x No atrazine	20.07b	0.00c	0.63bc	28.07b-d
With atrazine	0.00c	0.00c	1.50bc	10.32d
With AM x No atrazine	23.27b	0.00c	6.47a	40.82ab
With atrazine	0.00c	0.00c	4.70ab	13.64d
100 kg N ha^{-1} OF x No AM x No atrazine	33.83ab	0.00c	0.83bc	42.52ab
With atrazine	0.00c	1.47c	0.00c	10.44d
With AM x No atrazine	25.10ab	0.00c	1.07bc	35.06a-c
With atrazine	0.00c	1.63c	0.00c	9.80d
150 kg N ha^{-1} OF x No AM x No atrazine	24.40ab	0.00c	0.83bc	34.94a-c
With atrazine	0.00c	1.37c	0.00c	9.77d
With AM x No atrazine	34.70ab	0.00c	0.80bc	44.02ab
With atrazine	0.00c	5.50ab	0.00c	12.93d
NPK 15-15-15 x No AM x No atrazine	39.73a	0.00c	1.90bc	51.06a
With atrazine	0.00c	2.03bc	0.00c	10.36d
With AM x No atrazine	39.40a	0.00c	0.93bc	48.37a
With atrazine	0.00c	5.57ab	0.00c	12.52d
SE	5.53	1.31	1.46	6.59

AM = arbuscular mycorrhizal inoculation; Values within the same column, followed by similar letter(s) are not significantly different at $P < 0.05$ according to Duncan's Multiple Range Test.

Figure 1 showed maize roots AM colonization after the completion of the study. Arbuscular mycorrhizal colonization was observed in all the treatments. The AM colonization of the maize roots inoculated with *G. Clarum* (62.63-86.63%) was significantly higher than non-inoculated (22.00-41.93%). The application of organomineral and NPK fertilizers improved AM colonization in maize than the control. Also, across the fertilizer levels, AM inoculation alone increased AM colonization of maize roots than when AM inoculation was combined with atrazine application. Atrazine application to soil had little suppressive effects on AM colonization in the maize roots, regardless of the type of fertilizer or level of OF applied, except at 150 kg N ha^{-1} OF.

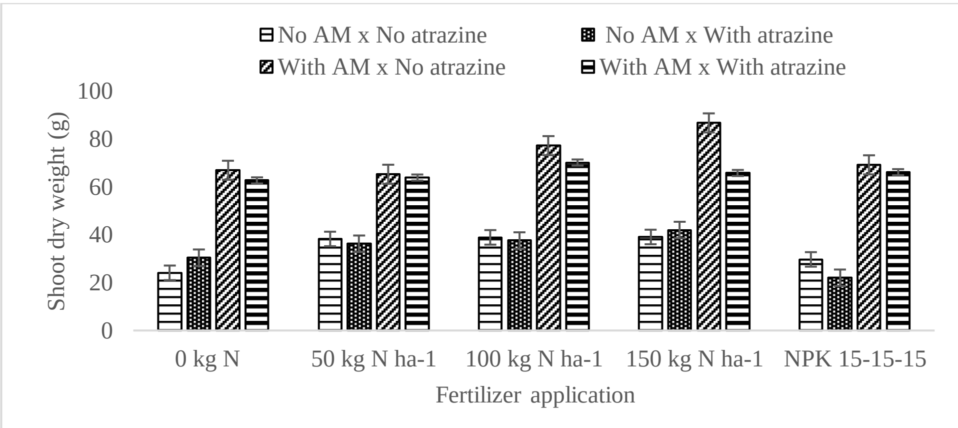

Figure 1. Arbuscular mycorrhizal colonization of maize root as influenced by the interactions of fertilizers, AM inoculation and atrazine application

There was varying degrees of significance in the concentration of N in maize ear leaf (Table 7). The highest N nutrient concentration in maize ear leaf was observed in the treatment involving 150 kg N/ha combined with AM inoculation alone, while the lowest was observed at 0 kg N combined with AM inoculation and atrazine. The concentration of N in maize ear leaf at 0 kg N showed that AM inoculation alone significantly increased N concentration compared to when AM inoculation was combined with atrazine. Similar observations were made at 50 and 150 kg N/ha OF, but without significance. The reverse was however observed at 100 kg N/ha OF and the application of NPK 15-15-15. Significantly higher P nutrient concentration in maize ear leaf was observed at 0 kg N combined with AM inoculation and atrazine compared to the other treatments. Across the fertilizer levels including NPK, the concentration of P in maize ear leaf were highest in the interactions involving atrazine alone than the other treatments. The concentration of K in maize ear leaf were significantly higher in the treatments involving 150 kg N/ha OF or NPK 15-15-15, each combined with AM inoculation and atrazine. The lowest K nutrient concentration in maize ear leaf was observed in the control. Across the OF levels, including fertilizer, combining AM inoculation with atrazine application improved K nutrient concentration in maize ear leaf than the contemporary treatments. There were significant variations among treatments with respect to Ca concentration in maize ear leaf. The highest concentration of Ca in maize ear leaf was observed at 50 kg N/ha OF combined with atrazine alone, while the lowest was observed in the control. The highest concentration of Ca at 0 kg N was observed in the treatment with AM inoculation alone. However, across the OF levels, combinations with atrazine alone gave higher Ca concentration in maize ear leaf than the other treatment combinations. The highest Ca nutrient concentration in maize ear leaf was observed in the treatment combining AM inoculation with atrazine. Magnesium nutrient concentration in maize ear leaf varied in their level of significance with respect to treatments applied. Applying 100 kg N/ha with AM inoculation and atrazine gave the highest Mg nutrient concentration in maize ear leaf, while the lowest was observed in the control. At 0 kg N and NPK fertilizer, combination with AM inoculation alone gave plant with higher Mg nutrient concentrations in maize ear leaf than the other treatments. However, at the other OF levels, combining AM inoculation with atrazine improved Mg nutrient concentration than the other treatments.

Table 7. Influence of fertilizers, AM inoculation and atrazine applications interactions on maize ear leaf nutrients concentration (%)

Treatments	N	P	K	Ca	Mg
0 kg N x No AM x No atrazine	7.33a-c	0.80c	1.37f	0.93h	1.03i
With atrazine	8.00a-c	1.54b	8.93de	2.40bc	1.80d-f
With AM x No atrazine	8.67a	1.19bc	10.67a-e	2.67b	2.30bc
With atrazine	6.00c	2.47a	10.87a-e	1.57fg	1.57f-h
50 kg N/ha OF x No AM x No atrazine	8.00aa-c	1.18bc	9.47c-e	1.60fg	1.40h
With atrazine	8.33ab	1.62b	12.43a-c	3.97a	1.80d-f
With AM x No atrazine	8.67a	1.41bc	11.50a-d	2.00c-f	1.67e-h
With atrazine	8.00a-c	1.52b	9.10de	1.80d-f	2.23bc
100 kg N/ha OF x No AM x No atrazine	6.33bc	1.01bc	10.00b-e	1.53fg	1.60e-h
With atrazine	8.33ab	1.45bc	12.97ab	1.93c-f	1.73d-g
With AM x No atrazine	8.00a-c	1.30bc	10.77a-e	1.80d-f	2.53ab
With atrazine	9.00a	1.25bc	12.67ab	1.97c-f	2.70a
150 kg N/ha OF x No AM x No atrazine	7.33a-c	1.34bc	11.83a-d	1.70ef	1.90de
With atrazine	8.67a	1.44bc	11.57a-d	2.20b-d	1.60e-h
With AM x No atrazine	9.33a	1.34bc	11.07a-e	1.80d-f	1.80d-f
With atrazine	8.00a-c	1.38bc	13.27a	2.10c-e	2.00cd
NPK 15-15-15 x No AM x No atrazine	8.00a-c	1.23bc	8.33e	1.13gh	1.63e-h
With atrazine	8.33ab	1.31bc	12.40a-c	1.83d-f	1.67e-h
With AM x No atrazine	8.00a-c	1.30bc	11.77a-d	1.20gh	1.90de
With atrazine	9.00a	1.19bc	13.13a	2.13c-e	1.47gh
SE	0.71	0.24	1.09	0.17	0.11

AM = arbuscular mycorrhizal inoculation; Values within the same column, followed by similar letter(s) are not significantly different at $P < 0.05$ according to Duncan's Multiple Range Test.

There was no significant difference in the response of maize to the residual effects of the interactions of the application of fertilizers, AM inoculation and atrazine (Figure 2). However, the residual effect of 100 kg N ha^{-1} combined with AM inoculation and atrazine gave the highest maize shoot dry weight. The residual effect of the control treatment gave the lowest maize shoot dry weight. Across the fertilizer levels, the residual effect of combining AM inoculation and atrazine gave higher maize shoot dry weight than the use of atrazine alone.

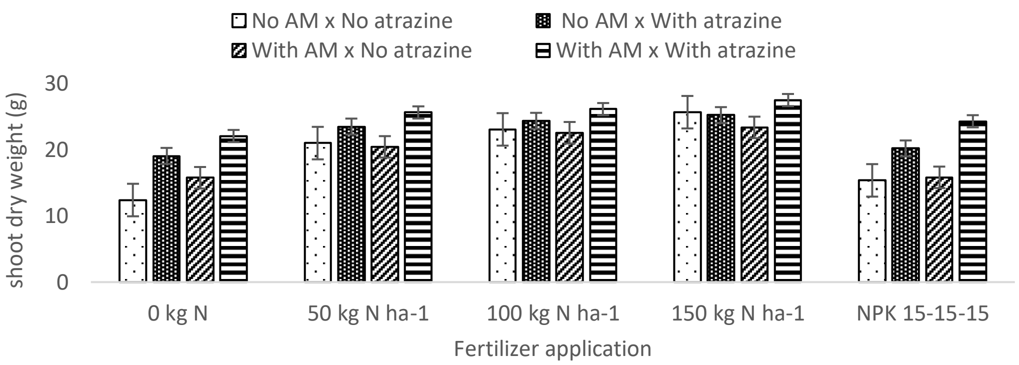

Figure 2. Residual maize shoot dry weight as influenced by the interactions of fertilizers, AM inoculation and atrazine application

Discussion

The textural classification of the soil physical fraction showed that the soil is loamy sand, indicating that it has a high amount of sand. According to Warncke et al. (2004), applying N fertilizer on such fine-textured soils have some economic advantages, but the environmental risks (leaching) generally out-weighed the economic benefits. The soil pH is high implying that it is alkaline in nature. Soil pH is critical to the efficacy of some herbicides (Warncke et al., 2004). Herbicide persistence in the soil is linked to the relationship between edaphic, climatic, and nature of herbicide (Fuscaldo et al. 1999). Findings suggest that persistence of atrazine, simazine and metribuzin in soil increased with high rates, low OM content and high pH (Fuscaldo et al., 1999; Warncke et al., 2004). Similarly, early reports have indicated that the pH of the soil has an impact on AM fungal density and diversity (Ouzounidou et al., 2015). Root colonization by inoculated fungi was stimulated at higher pH levels and inhibited at lower pH levels (Ouzounidou *et al*., 2015). It is therefore expected that the soil pH should favour root colonization by inoculated fungi. The low organic carbon observed in the soil is a characteristic of tropical soils (Kotschi, 2015). The pre-cropping soil organic carbon, nitrogen, available and exchangeable cation exchange capacity for the maize cultivation in Nigeria was considered low (Adeoye and Agboola, 1985). Similarly, Silva et al. (2011) demonstrated a direct relationship between reduced maize yield and soil nitrogen deficiency. For optimum maize production, N must be adequate during the growing season (Sileshi et al., 2010). As a consequence of these differences, it is logical to assume that there will be positive response of maize plants to the applied treatments.

The organomineral fertilizer used has N, K, Ca and Mg but low in P which on mineralization would be released for crop uptake. The values of organic carbon and C:N ratio of the material imply it is a good source of organomineral fertilizer to enhance crop performance through its effects on the soil's physical properties (Celik et al., 2004). According to Mooshammer et al. (2014), C:N ratios as observed in the OF may affect the dynamics of N, thereby, facilitating the rapid decomposition of organic matter and mineralization of N in the soils by microorganisms.

The reduction in the plant height at early growth stage (2 WAP) in all the treatments combined with atrazine but later increased at maturity was in support of Adigun and Lagoke (2003). They demonstrated atrazine depressive impact on the initial growth phases of maize plants, which showed a depressing impact of atrazine herbicides on maize plant height at the initial growth stages. They further supported the reports that at maturity, the depression disappeared and there was complete recovery in plant height at maturity. The results at maturity are also supported by the findings of Stefanovic et al. (2004), who reported that the use of herbicides not only suppresses weeds but also increased the height of maize plants. Across the OF levels including NPK 15-15-15 fertilizer at the early stage of growth, applied fertilizer did not suppress the influence of atrazine on maize plant height.

Unlike the responses observed on the other growth parameters, atrazine or its interactions with AM inoculation or fertilizers had no depressive effect at the early or maturity stages of the maize leaf area. This result was in support of findings made by Evans et al. (2003) that weed control increased leaf area. They reported that lower leaves of maize are suppressed by inappropriate weed control, which contributes to their early senescence, thereby leading to fewer numbers of leaves and consequently lower leaf area. Larbi et al. (2013) also reported similar finding on the weed competition for maize crops.

The highest dry shoot biomass observed in the interactions involving inorganic fertilizer suggests improved cell activity, enhanced cell multiplication and development of luxuriant vegetative plant compared to the organomineral fertilizer. However, the observed value was not significantly different from the values observed at 100 or 150 kg N/ha OF combined with AMF inoculation alone. This implies that the combinations were at par with inorganic fertilizer effect on maize dry shoot weight.

Higher grain yield observed in maize plants inoculated with AM fungi alone or atrazine alone compared to their interactions suggested their better influence when singly used to improve maize performance. The finding was in support of earlier reports by Celik et al. (2004) and Salami et al. (2005). They reported that the influence of AMF in improving plant growth diminishes with improvement in soil fertility status. Under Low P availability there is increases in plant demand for P and consequently increases in carbon allocation to AMF leading to improved AMF colonization and extra-radical hyphal development (Bending et al., 2004)., However, high P supply with high availability of other mineral nutrients, plants allocate relatively more photosynthate to shoots and leaves and less to roots and AMF, subsequently depressing AMF development (Liu et al., 2000; Treseder and Allen, 2002)

The improvement in N, Ca and Mg nutrition in maize by the application of AMF inoculation under the 0 kg N is in support of earlier report that inoculation with AMF increases these nutrients in crops (Liu et al., 2002; Fitter et al., 2011). Furthermore, the increase in N and K nutrient concentration observed in the treatment involving 150 kg N ha^{-1} with AMF inoculation implied a luxuriant consumption of N which resulted in vegetative growth at the expense of grain yield increment. The improved ear leaf nutrient concentration by atrazine application confirmed the report that maize has the ability to metabolize atrazine thereby improving its nutrition compared to where atrazine was not applied. Although combined effect of AMF and atrazine application improved K concentration, the lowest N nutrient concentration observed at 0 kg N combined with AMF inoculation and atrazine treatment must be due to the antagonistic effect of the combining AMF inoculation with atrazine. This finding is in support of Huang et al., 2007) that AMF hyphae trap atrazine in the root system of maize (Nedumpara et al., 1999), thereby not mobilized into the site where it can be metabolized to improve the plant growth and development. This trend of result continued across the different levels of OF application. This implied that the application of organomineral fertilizer had no substantial effect in altering the observed occurrence in maize. This probably explained the higher performances observed in these treatments during the residual planting, whereby the residual effects from combined application of AMF inoculation performing relatively better than the other treatment combinations across all fertilizer levels. The N, P, K, Ca and Mg nutrient concentrations observed at 100 kg N ha^{-1} OF with atrazine likely suggest a balanced nutrition for improved maize performance, as this was the treatment that optimizes maize yield.

The ability to check weeds at the early stage of growth has been reported to favour maize growth and development. The control of weeds through the application of atrazine or in combination with AMF inoculation supported this principle. Hence, the treatments favoured early weed suppression across all fertilizer treatments, thereby encouraging maize growth and yields. The relative increment in the total weed biomass resulting from sole application of mycorrhizal inoculation or combined with atrazine across the fertilizer levels suggest that AMF enhanced weed infestation despite the influence of atrazine. This may imply that the weeds species in the soil were sensitive to AMF inoculation, thereby promoting their growth and development. This finding was supported by the report published by Vatovec *et al*. (2005), that AMF inoculation increase some weed species performance. However, this growth improvement did not reduce maize performance, thereby diminishing yield as evident in the study.

Conclusions

The interactions of various agronomic practices with respect to crop performance is affected by soil amendments and the need for weed management in order to increase crop production require understanding. The application of organomineral fertilizer, NPK 15-15-15, AMF inoculation and atrazine enhanced ear leaf concentration, growth and yield in maize. Combining atrazine with AMF inoculation improved maize growth, reduced grain yield under organomineral fertilizer but the interaction differed under NPK fertilizer application. Atrazine application reduced AMF colonization in maize root. Dry weed biomasses at 4, 12 WAP and total dry weed biomass produced reduced in all treatments involving atrazine. The total dry weed biomass produced increased with AMF inoculation across fertilizer applications. Consequently, combining 100 kg N/ha OF with AMF inoculation or atrazine was recommended.

Compliance with Ethical Standards

Conflict of interest

The authors declared that for this article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the aurhors to the present study is equal. All the authors verify that the text, figures, and tables are original. The authors read and approved the final manuscript.

Ethical approval

Not applicable

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Not applicable

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