World Journal of Agricultural Research, 2023, Vol. 11, No. 1, 22-29
Available online at http://pubs.sciepub.com/wjar/11/1/4
Published by Science and Education Publishing
DOI:10.12691/wjar-11-1-4

Arbuscular Mycorrhizal Fungi Combined with Mineral Fertilizer Improved the Growth and Yield of Wheat (*Triticum aestivum* L.) Cultivated in the Western Highlands of Cameroon

Marie Solange Mandou[1,*], Nelson Ralph Anthony Biolo Modo[3], Asafor Henry Chotangui[1], Souleymanou Adamou[1,2], Mfangam Mfonte Raimatou[1], Julien Kevin Kedi A Fisseng[3], Swirri Christabel Shu Waa[1], Eric Bertrand Kouam[1]

[1]Genetics, Biotechnology, Agriculture and Plant Physiology Research Unit, Department of Crop Sciences, Faculty of Agronomy and Agricultural Sciences, University of Dschang, P.O. Box-222, Dschang Cameroon
[2]Regional Centre for Specialized Education in Agriculture, Forest and Wood, University of Dschang, Dschang, Cameroon
[3]Institute of Agricultural Research for Development of Bagangté, Bagangté, Cameroon
*Corresponding author: solangemandou@yahoo.fr

Received February 10, 2023; Revised March 13, 2023; Accepted March 24, 2023

Abstract Arbuscular mycorrhizal fungi (AMF) are beneficial for plant growth and development by facilitating the absorption of water and minerals from the soil. Symbiotic relationship between AMF fungi and plant roots is of paramount importance and could reduce crop production dependence on fertilizers. Nutrient deficiency in the soils of the western highlands of Cameroon especially N and P is a limiting factor to grain-filling in cereals. This study sought to investigate the effect of AMF combined with different levels of mineral fertilizer on the growth, root colonization and yield of wheat (*Triticum aestivum*). The experiment was conducted in a complete randomized block design arranged in split-plots using two varieties (Irad 1and Irad 2) and five treatments: control, F100%, AMF, AMF+F50% and AMF+F25% repeated three times. Results showed that all traits were significantly affected by treatments, except the plant height and spike length. Sole AMF treatment or in combination with low level fertilization (AMF+F25%) indicated better results for dry aboveground biomass, intensity of root colonization and yield. Contrarily, increased fertilization levels (F100% and AMF+F50%) reduced biomass, intensity of colonization and yield. No significant difference was observed between AMF and AMF+F25% treatments as well as between the two wheat varieties. These results suggest that wheat inoculation with AMF can reduce or simply replace the use of mineral fertilizer in wheat production in the western highlands of Cameroon.

Keywords: *AMF, Mineral fertilizer, root colonization, growth and yield, wheat*

Cite This Article: Marie Solange Mandou, Nelson Ralph Anthony Biolo Modo, Asafor Henry Chotangui, Souleymanou Adamou, Mfangam Mfonte Raimatou, Julien Kevin Kedi A Fisseng, Swirri Christabel Shu Waa, and Eric Bertrand Kouam, "Arbuscular Mycorrhizal Fungi Combined with Mineral Fertilizer Improved the Growth and Yield of Wheat (*Triticum aestivum* L.) Cultivated in the Western Highlands of Cameroon." *World Journal of Agricultural Research*, vol. 11, no. 1 (2023): 22-29. doi: 10.12691/wjar-11-1-4.

1. Introduction

Wheat (*Triticum aestivum* L.) is a cereal crop of the family *Poaceae*, and amongst the most cultivated in the world in terms of area and production after rice [1]. It is a staple food of nearly 70% of the world's population that is highly consumed in a variety of food products (bread, cookies, porridge, couscous…), animal feeding and biofuel production [2,3,4]. Increasing population in many African countries has resulted in an increase in wheat consumption as a staple crop in the past twenty years and such a move has been associated with changes in food preferences with urbanization [5]. The world production is estimated at 734 million tonnes [6] and production in Africa is relatively low (26 million tonnes) with Egypt being the leading producer of 9.4 million tonnes [6].

In Cameroon, wheat production was estimated in 2019 to be 900 tonnes annually, highly inferior to the country's demand. In the same year the country imported 955 thousand metric tonnes with an estimated import value of 185,914.00 US Dollar to fully satisfy the demand [7]. This suggests a high need to improve wheat production in the country. Based on the following, recommendations have been made to Government and non-governmental organizations to support and promote local wheat production in Cameroon [7].

The Agroecology of Cameroon is highly diversified with five different zones: Sudano-Sahel, Guinea Savanna, Bi-modal Equatorial, Mono-modal Equatorial and Western Highland. This agro-ecological diversity indicates the possibility to produce major crops grown in other African countries including wheat. [8] showed that prevailing climatic conditions in Cameroon is favorable zones for wheat cultivation. Generally, one of the limiting factors regulating the productivity of grain crops is availability of plant nutrients in soil. Particularly in acidic soils, phosphorus uptake is limited due to its tendency to complex with cations such as iron and aluminum rendering it unavailable to the plant [9]. Phosphorus and nitrogen deficiency due to unavailability deficiency is one of the main limiting factors in agricultural production [10], and in the case of wheat cultivation, this deficiency leads to poor grain filling and consequently yield reduction [11]. Grain-filling is the main constraint of wheat production in the western highlands of Cameroon. The application of nitrogen and phosphorus based fertilizers could be considered an efficient approach to improve grain-filling thereby improving the yield of cereals in low-nutrient soils. However, the high cost of these fertilizers makes them not affordable to poor resource farmers [12]. Also, its production requires high amounts of non-renewable energy resulting in greenhouse gases release in the atmosphere [13]. In addition, P efficiency use is low due to its fixation capacity in the soils [9]. In these situations, effective agronomic management is important, particularly, the management of soil microbiota including arbuscular mycorrhizal fungi (AMF) is an option to increase the availability and utilization of soil-derived nutrients [14].

AMF are soil microorganisms that belong to the phylum *Glomeromycota* and form symbiotic association with the roots of over 80% vascular plant species [15]. They are ubiquitous in soils around the globe and have been associated with improve plant growth for over 100 years through improved mineral absorption [16,17]. Many studies have reported that AMF was able to improve the absorption of minerals such as phosphorus, nitrogen and zinc [18]. In addition, AMF improves plant resistance to biotic and abiotic stresses [19]. Inoculation with AMF can supply up to 90% of plant P and 20% of plant N due to AMF extraradical hyphal network which ensures the intensive exploration of large soil volume [19, 20]. The degree of plant benefits from AMF inoculation depends, among others factors, on the nutrient conditions in the soil, especially the availability of nitrogen and phosphorus, which are considered the most restrictive nutrients for plants growth [21]. These two elements negatively affect AMF root colonization when they are present at high levels in the soil. The high P–fertilizer application decreases the supply of soluble carbohydrate in roots and hence reduces the appresorium formation and fresh infection [22]. Also, the arbuscle formation and active P transfer to plants is reduced in high P content in soils [23]. High applications of N fertilizer reduces AMF colonization in plants with mainly hyphal, vesicles and spore colonization only, though colonization intensity is low. However, the highest mycorrhizal efficiency was observed when the soil contained between 7.8 and 25 mg kg^{-1} of P [24]. In addition, low level of nitrogen increases the AMF colonization, plant growth and root formation [25].

The objective of the present study was to investigate the effect of AMF inoculation combined with different levels of N-P fertilizers on the growth and yield parameters of Wheat. The proposed study envisaged to test the hypothesis that combining AMF with mineral fertilizers would result in reducing fertilizer application and thus improve the profitability of farmers in subsistence cropping systems.

2. Materials and Methods

2.1. Description of the Study Site

The experiment was conducted at the Research and Application Farm of the Faculty of Agronomy and Agricultural Sciences of the University of Dschang, West region of Cameroon. The farm is located in the Western Highlands Agro-ecological Zone (Latitude 5.5° N, Longitude 10.05° E and Altitude of 1,410m) characterized by a rainy season that runs from mid-March to mid-November and a dry season that runs from mid-November to mid-March. The evolution of meteorological data recorded during the experiment (March 6th to July 17th 2020) are presented on Figure 1. The soil in the study site is ferralitic with chemical properties (0-20 cm layer) as follows: pH (H_2O) 5.5; carbon (%) 2.61; nitrogen ($g.kg^{-1}$) 0.46 and P Bray II (ppm) 2.66.

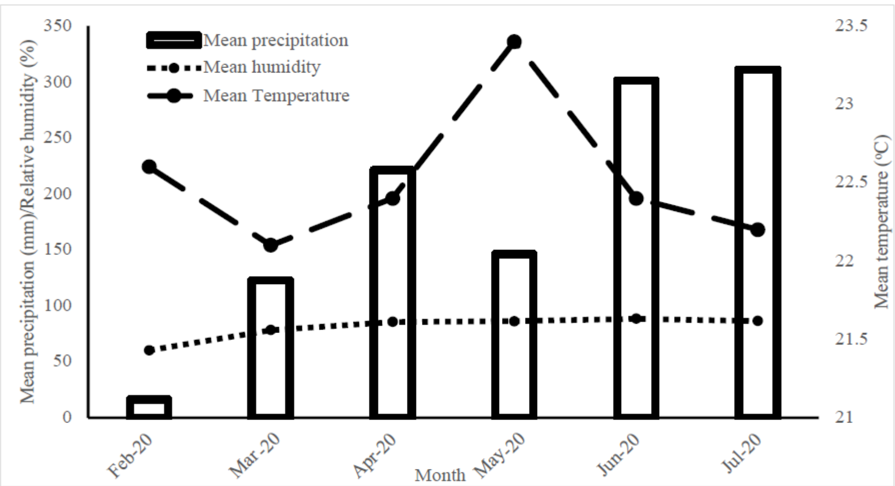

Figure 1. Climatic condition during the study period

2.2. Planting Material, AMF Inoculum and Fertilizers

Seeds of two wheat (*T. aestivum*) cultivars, Irad 1 and Irad 2, obtained from the Institute of Agricultural Research for Development (IRAD) Nkolbisson, Centre Region, Cameroon, were chosen based on their adaptation at high altitude (western highlands).

The biofertilizer (AMF inoculum) consisted of sandy soil, spores, hyphae and infected root segments of fungal genera *Glomus*, *Gigaspora* and *Acaulospora* at 200 propagules g^{-1} of inoculum obtained from GIC AGRIBIOCAM (Agriculture Biologique du Cameroun). Mineral fertilizers used in this study were urea (46% N) and NPK (20-10-10).

2.3. Experimental Design

A randomized complete block design arranged in split-plot with three repetitions including two cultivars (Irad 1 and Irad 2) as the main plots, and five treatments (Control, F100%, AMF, AMF+F50% and AMF+F25%) as the sub-plots, was adopted. F100% was the recommended fertilization for optimum wheat growth and development. Treatments are defined on Table 1.

Table 1. Description of Different Treatments

Treatments	Quantity
Control	0
F 100% (Mineral F 100%)	NPK (20-10-10): 600 kg. ha $^{-1}$
	Urea: 300 kg. ha^{-1}
AMF (AMF inoculation)	1200 propagules. plant^{-1}
AMF+F 50% (AMF inoculation + mineral F 50%)	NPK 2(0-10-10): 300 kg. ha $^{-1}$
	Urea: 150 kg. ha^{-1}
AMF +F 25% (AMF inoculation + mineral F25%)	NPK (20-10-10): 150 kg. ha $^{-1}$
	Urea: 75 kg. ha^{-1}

F: Fertilizer, AMF: Arbuscular mycorrhizal fungi.

2.4. Planting and Fertilizer Application

Two seeds hole^{-1} were manually sown at the depth of 2-3 cm. The planting distance was 25 cm between the lines and 15cm between plants, giving a planting density of 266667 plants ha^{-1}. At sowing, six grams of the AMF inoculum (1200 propagules) were placed in each planting hole. Split application was done for mineral fertilizers, the first, NPK (20-10-10) two weeks after sowing and the second, urea, at flowering, in the appropriate dose each. Weeds were controlled manually during the experiment.

2.5. Data Collection

Growth parameters were collected 8 weeks after planting (WAP) on eight randomly chosen plants. Data were collected on plant height, number of tillers, dry aboveground biomass and AMF root colonization. At harvest (20WAP), the number and the length of spikes were measured. The seeds from each plant were collected, counted and weighed to determine the dry weight per plant and of 1000 seeds. Yield was calculated using the formula:

$$\frac{Grain\ weight\ (g)\ x10000}{Harvested\ area\ \left(m^2\right)\ x1000\left(g.kg^{-1}\right)} \qquad (1)$$

AMF root colonization was assessed on roots from five randomly selected plants in the middle of each plot. Root colonization was determined on root subsamples. Roots were cut into 1-2 cm pieces, stored in 10% KOH overnight at room temperature. They were washed several times with de-ionized water and soaked in alkaline 3. 5 % H_2O_2 for 30 minutes [26]. The roots were subsequently stained at room temperature for 45 minutes with a solution of blue ink (Parker^P Quink®) diluted in 1 % HCl at 1:50 proportions [27]. Thirty root fragments (1 cm long) of each root subsample (from 5 plants) per treatment were considered to estimate treatment means. For each fragment, the abundance and diversity of the mycorrhizal structures (Arbuscules, vesicles, intracellular hyphae, auxiliary cells and spores) were noted. The frequency (F%: the percentage of root fragments that contains either hyphae, arbuscules or vesicles/spore) and the intensity (I%: the abundance of hyphae, arbuscules or vesicles/spores in the root system) of the mycorrhization were evaluated as described by [28].

2.6. Data Analysis

All data collected were subjected to analysis of variance (ANOVA) using the R software. Differences between treatments were separated using Fisher's least significant difference (LSD) at a probability threshold of 5%. Pearson's correlation analysis was performed for growth and yield parameters in SPSS version 21.

3. Results and Discussion

3.1. Growth Response of Wheat to AMF Combined with Different Levels of Mineral Fertilizers

Results showed that wheat growth represented by the number of tillers and dry aboveground biomass indicated significant differences between the varieties, treatments and interactions (variety x treatment) (Table 2). The plant height was not significantly affected by treatments and varieties. The assessment of plant height was done probably before the complete establishment of the symbiosis and thus could reduce the possibility of detecting significant differences among treatments. [29] observed that the development of AMF symbiosis on upland rice in the field started 3 weeks after sowing. Moreover, plant height may be a genetically-mediated character. In addition, similar results were obtained on ryegrass [30]. However, the interaction between variety and treatment was significant ($P<0.05$). The maximum plant height (93.85cm) was observed in Irad 1 for the treatment AMF+F50% and the minimum heights (72.75cm and 77.76cm) for the control and AMF+25% treatments of Irad 2, respectively. The number of tillers per plant was significantly affected by the fertilizer treatments. The maximum number of tillers was observed on AMF (15) and AMF+F25% (15) of Irad 1. The same trend was observed for Irad 2 with 19 and 16 tillers for AMF and AMF+F25% treatments, respectively. Increased mineral fertilizer application in AMF inoculated plants (AMF + F50%) reduced the number of tillers to 13 and 15 for Irad 1 and Irad 2, respectively as compared to AMF and AMF+F25% (Table 2). However no significant difference was observed between the AMF+F50% and F100% treatments. The lowest number of tillers was obtained in the control treatments independent for the variety.

The dry aboveground biomass followed the same trend with the highest biomass obtained in AMF (204.77g and 347g) and AMF+F25% (204 77g and 349g) for Irad 1 and Irad 2, respectively. Similarly, the lowest biomass was obtained in the control treatments for both varieties. Thus, AMF inoculation or inoculation with 25% fertilizer significantly improves wheat (Irad 1 and Irad 2) growth in terms of number of tiller and dry aboveground biomass.

Vegetative growth mostly relies on N availability and many scientists have reported the role of AMF in nutrient uptake from the soil nutrients, especially N, which can effectively promote the growth of the host plant [31]. In addition, the number of tillers and dry aboveground biomass were strongly correlated to the intensity of root colonization suggesting that the extra radical mycelium formed after the establishment of intraradical structures (especially arbuscules) can effectively improve nutrient uptake, thereby improving plant growth and development [32]. The results are in agreement with those of [33] who showed that the root colonization levels were positively correlated to the growth of tomato. The increase in fertilization level improves the soil nutrient availability and the plant can directly absorb enough nutrients to reduce its dependency on AMF symbiosis, resulting to lower plant growth. Similar results were also observed on maize [34].

3.2. AMF Root Colonization

Mycorrhizal colonization was observed in both AMF inoculated and non-inoculated plants whatever the fertilization level. The colonization frequency in wheat roots is significantly influenced by applied fertilization for the two cultivars (Figure 2). In the non-inoculated treatments (control and F100%), the values were considered high and varied from 63% to 77% suggesting the occurrence and the acceptance potential of the soil native strains of AMF of the two cultivars. This is due to the ubiquitous character of AMF which can form symbiotic association with the roots of over 80% of terrestrial plants [15]. But the frequency of mycorrhizal colonization was significantly high in the inoculated plants.

Table 2. Growth Response of wheat to AMF Combined with Different Levels of Mineral Fertilizers

Variety	Treatments	Plant height (cm)	N$^{o.}$ of tillers plant^{-1}	Dry aboveground biomass (g. plant^{-1})
Irad 1	Control	86.16ab	12d	144.22^{e}
	F100%	83.96ab	14bcd	175.66de
	AMF	84.20ab	15bc	204.77bcd
	AMF+F50%	93.85a	13cd	155.44^{e}
	AMF+F25%	90.32ab	15bc	204.77bcd
	Mean	87.70	14	181.22
Irad 2	Control	72.75b	11d	140.11e
	F100%	82.77ab	14bcd	242.22bc
	AMF	92.30ab	19a	347.22a
	AMF+F50%	90.45ab	15bc	171.22de
	AMF+F25%	77.76b	16b	349.66a
	Mean	83.21	15	250.09
Variety		ns	s	s
Treatment		ns	s	s
Variety*Treatment		s	s	s

F: Fertilizer NPK (20-10-10) + Urea, AMF: Arbuscular mycorrhizal fungi, ns: not Significant, s: Significant. Values followed by the same letter on the same column are not significantly different according LSD test at 5% probability level.

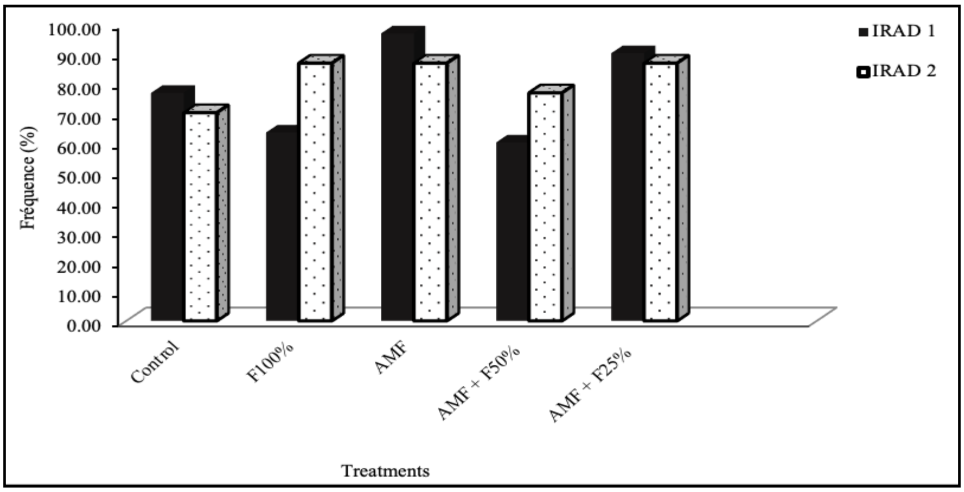

Figure 2. Frequency of AM root colonization

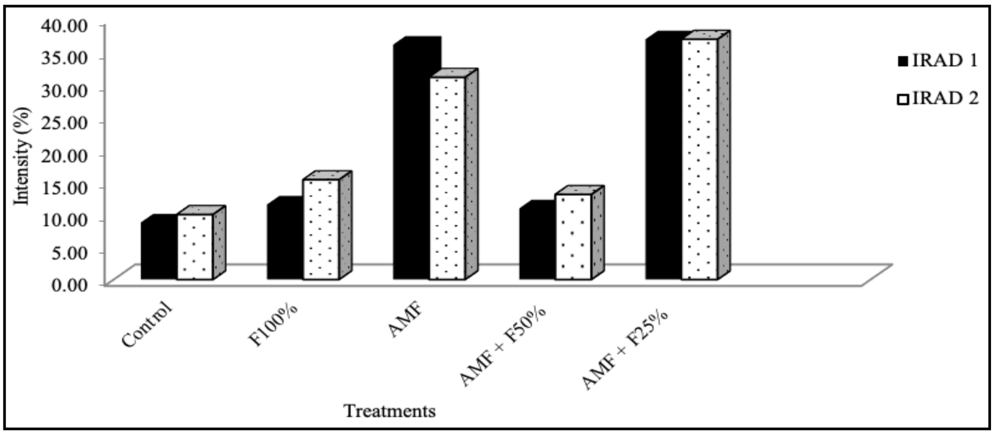

Figure 3. Intensity of AMF root colonization

The highest frequency was observed in AMF treatment (96% and 86% Irad 1 and Irad 2, respectively) and AMF+F25% (90% and 86% for Irad 1 and Irad2, respectively). High fertilization level (F100% and AMF +F50%) had a significant negative impact on the frequency of root colonization especially for Irad 2 compared to low fertilization level (AMF and AMF+F25%). Unfortunately, the frequency of root colonization is not the efficient variable for mycorrhizal colonization evaluation. The intensity of colonization represents the entire transport network that will provide the potential quantities of nutrients available to the plant. When root cells are penetrated by hyphae, they branch and form arbuscules, which improve the nutrient exchange between partners [35]. Root infection intensity was significantly influenced by treatments (Figure 3).

AMF inoculation alone (AMF) or combined with 25% fertilizer (AMF+F25%) increased significantly the intensity of root colonization by 30% over the control in both varieties. AMF recorded 36% and 31% for Irad 1 and Irad 2, respectively while AMF+F25% showed 36% in both varieties. Increasing the level of fertilizer from 25 to 50% (AMF+F50%) reduced the colonization intensity (from 30% to 12%) compared to AMF and AMF +F25%. This is in agreement with the findings of [36] for durum wheat under field condition who found a reduction in mycorrhizal root colonization in plants grown in nutrient-rich soils. Excessive fertilization significantly reduced the AMF colonization due to the higher nutrient availability in the soil after the chemical addition [37].

In this condition the plant is better able to satisfy its nutritional needs without having to transfer photosynthates to the mycorrhizae and thus reduce the AMF colonization [38].

Contrarily, in low fertilizer conditions, the plant is stimulated to develop a symbiotic relationship to increase its chances of intercepting more nutrients. However no significant difference was observed between Control, F100% and AMF+F50% and between the cultivars.

3.3. Yield Components and Yield

Data on yield components (number of spikes per plant, spike length and number of grains per plant) are shown on Table 3. The number of spikes per plant contributes directly towards yield. Results indicated that the highest number of spikes were obtained in AMF (10 and 12) and AMF+F25% (10 and 11) treatments for Irad 1 and Irad 2, respectively (Table 3). Increasing the fertilizer level from 25% to 50% and 100% result to significantly decrease in the number of spikes per plant for both varieties. Also, the spike length showed a similar trend. Data regarding the number of grains per plant indicated that all the mycorrhizal inoculation treatments had the highest number of grains per plant (630, 586 and 551 for AMF, AMF+F50% and AMF+F 25%, respectively) for Irad 1. There was a slight difference for Irad 2 with 776 grains per plant for the obtained AFM+F25% treatment (Table 3).

Analysis of variance revealed that grain weight per plant, the weight of 1000 grains and yield were significantly enhanced over the control treatment for both cultivars (Table 4). Grain weight per plant and the weight of 1000 grains showed the highest values in AMF and AMF+F25% and the lowest in the control treatments. The yield in F100% (3.11t. ha^{-1} and 3.24t. ha^{-1} for Irad 1 and Irad 2, respectively) was significantly similar to that of AMF+F50% (3.29t. ha^{-1} and 3.47t. ha^{-1} for Irad 1 and Irad 2, respectively). The AMF and AMF+F25% treatments significantly produced higher yield over control treatments. The AMF produced grain yield of 5.82t. ha^{-1} and 5.17 t. ha^{-1} for Irad 1 and Irad 2, respectively while AFM+F25% yielded 5.64t. ha^{-1} and 5.33t. ha^{-1} grain for Irad 1 and Irad 2, respectively. The lowest yield was obtained in the control treatments for both cultivars.

The percentage increase produced by AMF alone was 150% and 125% over the control for Irad 1 and Irad 2, respectively. AMF associated with 25% fertilizer (AMF+F25%) increased yield by 144% and 132% over the control for Irad 1 and Irad 2, respectively. There was a significant interaction effect ($P<0.05$) between variety and treatment on grain weight per plant, 1000grains weight and yield (Table 4). Results showed that AMF inoculation alone or combined with 25% mineral fertilizer improve wheat grain yield by at least 100%. Thus, limiting chemical sources of nutrients stimulates plants in the development of a highly permissive root system toward symbionts and the more efficient exploitation of soil resources [39]. Moreover, the application of F100% reduced grain yield by 80% over AMF treatment. Interestingly, no significant difference was observed between these treatments suggesting the possible replacement of mineral fertilizer by AMF inoculation. Many authors, demonstrated that increased photosynthetic activities and other leaf functions are directly related to improved growth frequency of AMF inoculation that is directly linked to the uptake of N, P, and carbon, which could promote the development of spikes. [40] have demonstrated AMF-mediated increased allocation of shoot biomass to spikes and grains through increased N and P redistribution to spike particularly under low fertilizer levels. N and P are considered nutrients mediating grain filling and yield increase of cereals in low nutrient soils. Plants colonized with AMF are able to produce extensive underground extraradical mycelia ranging from the roots up to the surrounding rhizosphere, thereby helping in improving the uptake of nutrients specifically N and P [41]. Results obtained in this study corroborates that obtained in the inoculation of maize, durum wheat and tomato [34,36,39].

3.4. Correlation Analysis

Pearson's correlation analysis showed significant correlations among the variables studied (Table 5). The number of spikes per plant showed significant positive correlation with number of tillers per plant (0.984^{**}). The aboveground biomass was positively correlated with number of tillers (0.837^{**}) and number of spikes (0.868^{**}) at high level of significance. Grain yield had highly significant positive correlation with number of tillers (0.76^{*}), number of spikes (0.73^{*}), aboveground biomass (0.65^{*}) but had highly significant positive correlation with spike length (0.82^{**}), grain weight per plant (1.00^{**}) and thousand grain weight (0.97^{**}). These results were in agreement with [42]. For arbuscular root colonization, the results showed that the intensity root colonization was significantly correlated with plant growth parameters and highly correlated with yield and yield component (Table 5). These findings are supported by the other scientists of the world. The development of plant growth and the increment of yield are linked to the increased uptake of minerals especially N and P, and other beneficial traits helping extraradical mycelium exchange nutrients toward roots [33,34].

Table 3. Yield components of wheat

Variety	Treatments	Weight (g)		Yield ($t.ha^{-1}$)
		Grains $plant^{-1}$	1000 grains	
Irad 1	Control	8.66^{e}	33.66c	2.31c
	F100%	11.66d	39.93b	3.11b
	AMF	21.83a	49.00a	5.82a
	AMF+F50%	12.33d	40.50b	3.29b
	AMF+F25%	21.16a	51.76a	5.64a
	Mean	11.21	42.97	4.03
Irad 2	Control	8.58e	33.33c	2.29c
	F100%	12.16d	41.33b	3.24b
	AMF	19.41a	51.63a	5.17a
	AMF+F50%	13.00cd	41.83b	3.47b
	AMF+F25%	20.00a	51.96a	5.33a
	Mean	14.63	44.02	3.90
Variety		ns	ns	ns
Treatment		s	s	s
Variety*Treatment		s	s	s

F: Fertilizer NPK (20-10-10) + Urea, AMF: Arbuscular mycorrhizal fungi, ns: not Significant, s: Significant. Values followed by the same letter on the same column are not significantly different according LSD test at 5% probability level.

Table 4. Grain yield of wheat

Variety	Treatments	N° of spikes $plant^{-1}$	Spike length (cm)	N° of grains $plant^{-1}$
Irad 1	Control	8d	7.11abc	466b
	F100%	9bcd	8.54abc	531b
	AMF	10bc	9.88ab	630ab
	AMF+F50%	9cd	8.87abc	586ab
	AMF+F25%	10bc	9.69ab	551ab
	Mean	9	8.82	553
Irad 2	Control	7d	7.51abc	405b
	F100%	10bcd	7.92abc	612ab
	AMF	13a	9.61ab	508b
	AMF+F50%	10bc	7.80 abc	540ab
	AMF+F25%	11b	8.19abc	776a
	Mean	10	8.20	568
Variety		s	ns	ns
Treatment		s	s	s
Variety*Treatment		s	s	s

F: Fertilizer NPK (20-10-10) + Urea, AMF: Arbuscular mycorrhizal fungi, ns: not Significant, s: Significant. Values followed by the same letter on the same column are not significantly different according LSD test at 5% probability level.

Table 5. Pearson correlation between growth and yield parameters

	Plant height (cm)'	No. of tillers plant^{-1}	No. of spikes plant^{-1}	Spike length (cm)	AG biomass (g)	No. of grains plant^{-1}	WT of grains plant^{-1}	WT of 1000 grains (g)	Yield (t. ha^{-1})	Int. of root colonization (%)
Plant height (cm)'	1.00									
No. of tillers plant^{-1}	0.42	1.00								
No. of spikes plant^{-1}	0.44	**0.984****	1.00							
Spike length (cm)	0.46	0.62	0.59	1.00						
AG biomass (g)	0.00	**0.837****	**.868****	0.36	1.00					
No. of grains plant^{-1}	-0.04	0.42	0.48	0.27	0.59	1.00				
WT of grains plant^{-1}	0.13	**0.82****	**0.77***	**0.80****	0.61	**0.69***	1.00			
WT of 1000 grains (g)	0.29	**0.86****	**0.85****	**0.77****	**0.77****	**0.64***	**0.97****	1.00		
Yield (t. ha^{-1})	0.23	**0.76***	**0.73***	**0.82****	**0.65***	0.59	**1.00****	**0.97****	1.00	
Int. of root colonization (%)	.056	**0.69***	**0.67***	**0.72***	**0.69***	0.58	**0.97****	**0.94****	**0.97****	1.00

*Correlation at 0.05 significant level, **Correlation at 0.01 significant level.

4. Conclusion

The present study showed that the AMF-inoculation alone or with 75% reduction of the recommended quantity of mineral fertilizer has the potential to improve the growth, AMF root colonization and grain yield of wheat in the western highlands Cameroon. AMF and AMF combined with 25% recommended mineral fertilizer gave significantly the same grain yield, suggesting that AMF can replace mineral fertilizer in wheat production at the level of the field. Consequently, the AMF inoculation could be used in wheat production in the Western Highlands of Cameroon to reduce mineral fertilization applications thereby reducing production cost and limiting environmental issues associated with chemical fertilizers. This will in return reduce the cost of farm inputs while enhancing wheat production through optimization of biological resources. Thus, it could be used as an eco-friendly approach to improve wheat production in the country and for the enhancement of global food production.

Acknowledgements

The authors are grateful for material and scientific contributions of members of the Genetics, Biotechnology, Agriculture and Plant Physiology Research Unit of the University of Dschang. Other support not mentioned are equally appreciated.

References

[1] Mohsen, K.H., AL-Asady, K.K.G. and AL-abody, M.A.K. The effect of spraying from macro and micro nutrients trace elements as a solution on yield and its component of wheat (*Triticum aestivum* L.) under Basrah environmental conditions. *Muthanna Journal of Agricultural Sciences*. 2 (2). 1-11. 2014.

[2] Nknam B. Evaluation of yield and some morphological traits of wheat under drought stress. *Indian J of Fund and Appl Lied. Life Sci*, 4 (2). 2231-6345. 2014.

[3] Debiton, C. Identification des critères du grain de blé (*Triticum aestivum* L.) favorables à la production de bioéthanol par l‟étude d‟un ensemble de cultivars et par l'analyse protéomique de lignées isogéniques waxy. Thèse. Doct. Univ Blaise Pascal, 276p, 2010.

[4] Abecassis, J., Delenne, J.Y., Mabille, F., Sadoudi, A., Samson, M.F., Lullien-Pellerin V. Expérimentation et modélisation pour la compréhension des mécanismes de fractionnement des céréales. *Innovations Agronomiques* 19. 95-105. 2012.

[5] Macauley, H., 2015. Cereal Crops: Rice, Maize, Millet, Sorghum, Wheat An Action Plan for African Agricultural Transformation. United Nations Economic Commission for Africa, Background Paper, Pp. 21-23.

[6] FAO. Suivi de la sécurité alimentaire et la nutrition à l'appui du Programme de développement durable à l'horizon 2030: Bilan et perspectives. Rome, FAO. 24p. 2016.

[7] Shilliea, P.N., Egwua, M.J.B. and Bojab, N.M. Rethinking wheat importation in Cameroon: an estimation of likely benefits missed due to importation. *Food & Agribusiness Management*. 3(1). 12-19. 2022.

[8] Rajaram, S. and Hettel, G.P. Wheat Breeding at CIMMYT: Wheat special report No 29. Ciudad Obregon, Sonora, Mexico 21-25 March, 1994.

[9] Fink, J.R., Inda, A.V., Bavaresco, J., Barrón, V., Torrent, J. and Bayer, C. Adsorption and desorption of phosphorus in subtropical soils as affected by management system and mineralogy. *Soil & Tillage Research*. 155. 62-68. 2016a.

[10] Holdford, I.C.R., Schweitzer, B.E. and Crocker, G.J. Long –term effects of lime on soil-phosphorus solubility and sorption in the height acidic soils. *Australian Journal of Soil Research* 32 (4). 795-803. 1994.

[11] Boukhalfa-Deraoui, N., Hanifi-Mekliche, L. and Mihoub, A. Fertilization practices can contribute to modify the properties of the soils, in particular salinity and the pH of soils. The main goal of this study is to demonstrate the impact of the physicochemical properties physicochemical properties Subject Category: Properties. *Journal of Agriculture Research.* 9 (3). 123-131. 2015.

[12] Nziguheba, G., Zingore, S., Kihara, J., Merckx, R., Njoroge, S., Otinga, A., Vandamme, E. and Vanlauwe, B. Phosphorus in smallholder farming systems of sub-Saharan Africa: Implications for agricultural intensification. *Nutrient Cycling in Agroecosystems*. 104(3). 321-340. 2016.

[13] Jenssen T.K. and Kongshaug G. Energy consumption and greenhouse gas emissions in fertilizer production. Proceeding, 509: 1-28. York, International Fertilizer Society. 2003.

[14] Cardoso Filho, J. A., Sobrinho, R. R. and Pascholati, S. F. Arbuscular mycorrhizal symbiosis and its role in plant nutrition in sustainable agriculture. In *Agriculturally Important Microbes for Sustainable Agriculture*. pp. 129-164. Springer. 2017.

[15] Wang, B., and Qiu, Y.L. Phylogenetic distribution and evolution of mycorrhizas in land plants. *Mycorrhiza*. 16(5). 299-363. 2006.

[16] Hamel, C. Prospects and problems pertaining to the management of arbuscular mycorrhizae in agriculture. *Agric. Ecosyst. Environ.* 60. 197-210. 1996.

[17] Singh, R. and Adholeya, A. Diversity of AM (Arbuscular mycorrhizal) fungi in wheat agro-climatic regions of India. *Virol Mycol*. 2(116). 517-2161. 2013.

[18] Ardakani, M.R., Pietsch, G., Moghaddam, A., Raza, A. and Friedel, J.K. Response of root properties to tripartite symbiosis between lucerne (Medicago sativa L.), rhizobia and mycorrhiza under dry organic farming conditions. *American Journal of Agricultural and Biological Science*. 4(4). 266-277. 2009.

[19] Smith, S.E. and Read, D.J. Mycorrhizal Symbiosis, 3rd ed, Academic Press, London, UK. 800p. 2008.

[20] Smith, S. E. and Smith, F.A. Roles of Arbuscular Mycorrhizas in Plant Nutrition and Growth: New Paradigms from Cellular to Ecosystem Scales. *Annu. Rev. Plant. Biol*. 62. 227-250. 2011.

[21] Aggarwal, A., Kadian, N., Tanwar, A. Yadav, A. and Gupta, K.K. Role of arbuscular mycorrhizal fungi (AMF) in global sustainable development. *Appl. Nat. Sci*. 3 (2). 340 -351. 2011.

[22] Lopez-Raez, J.A., Shirasu, K. and Foo, E. Strigolactones in plant interactions with beneficial and detrimental organisms: the Yin and Yang. *Trends Plant Sci*. 22. 527-537. 2017.

[23] Kobae, Y., Ohmori, Y. Saito, C. Yano, K., Ohtomo, R. and Fujiwara, T. Phosphate treatment strongly inhibits new arbuscule development but not the maintenance of arbuscule in mycorrhizal rice roots. *Plant Physiol*. 171. 566-579. 2016.

[24] Balota, E.L., Machineski, O. and Scherer, A. Mycorrhizal effectiveness on physic nut as influenced by phosphate fertilization levels. *Rev. Bras. Cienc. Solo* 36 (1). 23-32. 2012.

[25] Lin, C., Wang, Y., Liu, M., et al., Effects of nitrogen deposition and phosphorus addition on arbuscular mycorrhizal fungi of Chinese fir (*Cunninghamia lanceolata*). *Sci*. *Rep*. 10. 12260. 2020.

[26] Koske, R.E. and Gemma, J.N. A Modified Procedure for Staining Roots to Detect VA Mycorrhizas. *Mycological Research*. 92. 486-488. 1989.

[27] Vierheilig, H. and Piché, Y. A. Modified procedure for staining arbuscular mycorrhizal fungi in roots. *Z. Pflanz. Bodenkd*. 161. 601-602. 1998.

[28] Trouvelot, A., Kough, J.L. and Gianinazzi-Pearson, V. Estimation of vesicular arbuscular mycorrhizal infection levels. Research for methods having a functional significance. In *Physiological and Genetical Aspects of Mycorrhizae: Aspects Physiologiques et Genetiques des Mycorhizes*, Proceedings of the 1st European Symposium on Mycorrhizae, Dijon, France, 1-5 July 1985; Institut National de le Recherche Agronomique: Paris, France. 1986.

[29] Wissuwa M., Gonzalez, D. and Watts-Williams, S. J. The contribution of plant traits and soil microbes to phosphorus uptake from low-phosphorus soil in upland rice varieties. *Plant and Soil* 448. 523-537. 2020.

[30] Chen, J., Guo, J., Yang, Z., Yang, J., Dong, H., Wang, H., Wang, Y. and Zhan, F. The Application of Fertilizer and AMF Promotes Growth and Reduces the Cadmium and Lead Contents of Ryegrass (*Lolium multiflorum* L.) in a Copper Mining Area. *Phyton-International Journal of Experimental Botany*, 92 (2). 472-485. 2023.

[31] Smith, S.E., Jakobsen, I., Grønlund, M. and Smith, F.A. Roles of arbuscular mycorrhizas in plant phosphorus nutrition: Interactions between pathways of phosphorus uptake in arbuscular mycorrhizal roots have important implications for understanding and manipulating plant phosphorus acquisition. *Plant Physiol.* 156, 1050-1057. 2011.

[32] Lehmann, A., and Rillig, M. C. Arbuscular mycorrhizal contribution to copper, manganese and iron nutrient concentrations in crops: a meta-analysis. *Soil Biol. Biochem.* 81. 147-158. 2015.

[33] Ziane, H., Meddad-Hamza, A., Beddiar, A. and Gianinazzi, S. Effects of Arbuscular Mycorrhizal Fungi and Fertilization Levels on Industrial Tomato Growth and Production. *Int. J. Agric. Biol.* 19. 341-347. 2017.

[34] Fall, A.F., Nakabonge, G., Ssekandi, J., Founoune-Mboup, H., Badji, A., Ndiaye, A., Ndiaye, M., Kyakuwa, P., Anyoni, O.G., Kabaseke, C., Ronoh, A.K. and Ekwangu, J. Combined Effects of Indigenous Arbuscular Mycorrhizal Fungi (AMF) and NPK Fertilizer on Growth and Yields of Maize and Soil *Nutrient Availability Sustainability* 15. 2243. 2023.

[35] Peterson, R.L. and Massicotte, H.B. Exploring structural definitions of mycorrhizas, with emphasis on nutrient-exchange interfaces *Canadian Journal of Botany*. 88(8).1074-1088. 2004.

[36] Felföldi, Z. Vidican, R., Stoian, V., Roman, I.A., Sestras, A.F., Rusu, T. and Sestras, R.E. Arbuscular Mycorrhizal Fungi and Fertilization Influence Yield, Growth and Root Colonization of Different Tomato Genotype. *Plants*. 11. 1743. 2022.

[37] Zhang, X., Wang, L.; Ma, F., Yang, J. and Su, M. Effects of arbuscular mycorrhizal fungi inoculation on carbon and nitrogen distribution and grain yield and nutritional quality in rice (*Oryza sativa* L.). *J. Sci. Food Agric*. 97. 2919-2925. 2017.

[38] Liu, J., Zhang, J., Li, D., Xu, C. and Xiang, X. Differential responses of arbuscular mycorrhizal fungal communities to mineral and organic fertilization. *Microbiology Open*. 9. e00920. 2019.

[39] Ercoli, L., Schuler, A., Arduini, I., and Pellegrino, E. Strong increase of durum wheat iron and zinc content by field-inoculation with arbuscular mycorrhizal fungi at different soil nitrogen availabilities. *Plant Soil*. 419. 153-167. 2017.

[40] Zhang, S., Luo, P., Yang, J., Irfan, M., Dai, J., An, N., Li, N. and Han, X. Responses of Arbuscular Mycorrhizal Fungi Diversity and Community to 41-Year Rotation Fertilization in Brown Soil Region of Northeast China. *Front. Microbiol*. 12. 2941. 2021.

[41] Battini, F., Grønlund, M., Agnolucci, M., Giovannetti, M. and Jakobsen, I. Facilitation of phosphorus uptake in maize plants by mycorrhizosphere bacteria. *Sci. Rep*. 7. 4686. 2017.

[42] Ojha, B.R. On-farm evaluation of yield and yield attributing traits of promising wheat genotypes at mid western hills of Nepal. *Journal of Plant Breeding* 7: 3-14. 2012.