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Review Article

Constraints to cotton production in sub-Saharan Africa and the potential of rape oil based insecticide as well as Bacillus amyloliquefasciens for pests management and improvement of cotton yield

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Abstract

In French-speaking African countries such as Benin, Mali, Burkina Faso, Chad and Togo, the cotton sector is one of the main drivers of the national economy. This sector unfortunately faces agronomic and entomological constraints such as poor soil fertility as well as pest damages which causes a drastic drop in its production. The intensive use of mineral fertilizers and chemical insecticides to remedy these constraints has led respectively to a decline in soil fertility and the development of the phenomenon of resistance among pest populations. In addition, the late onset of rains in recent years has required increasingly late sowing, leading to very high losses incurred by cotton farmers. It is therefore urgent to consider the use of alternative products for cotton cultivation. In that perspective, rapeseed oil and the rhizobacterium *Bacillus amyloliquefaciens* FZB 42 can be considered. This article is a literature review that summarizes the constraints linked to cotton production in sub-Saharan Africa and highlights the potential of rapeseed oil based insecticides as well as rhizobacterium *B. amyloliquefaciens* FZB 42 for cotton production.

1. Introduction

The cotton plant (*Gossypium hirsutum L., 1763*) is the main cultivated textile plant in the world and constitutes more than 50% of the fiber market [1]. Ton [2] estimates that nearly 8 million people are involved in the cotton sector in West and Central Africa. More than two million farmers cultivate an average of one hectare of cotton in West Africa [3]. This crop provides more than 50% of financial resources to rural populations and therefore contributes considerably to the fight against poverty in cotton-producing countries [4].

The cotton sector is one of the main drivers of the national economy in French-speaking African countries such as Benin, Mali, Burkina Faso, Chad and Togo [5]. In Benin for instance, more than 325,000 producers cultivate cotton, supporting around 2 million people [6, 7]. Cotton remains the main export crop, which contributes to the socio-economic development of Benin with 70% to 80% of export revenues, 35% of tax revenues and a contribution in terms of added value estimated at 13% of GDP [8]. This sector, which constitutes a privileged tool for combating poverty, unfortunately finds itself confronted with agronomic constraints which reduce its national production. The decline in soil fertility, the failure to control pests and climatic hazards are the major constraints on cotton cultivation which have led to a drastic drop in production [9,10]. In sub-Saharan

Africa, cotton is grown on tropical ferruginous and ferralitic soils. The poverty of these soils has led stakeholders to set up a mineral fertilization program which provides 200 kg of mineral fertilizer per hectare each year. According to the IFDC [11], chemical fertilizers applied to conventional cotton plots cost around 47,000 FCFA/ha. Which is too high for farmers with low incomes. In addition to this high cost, the intensive use of mineral fertilizers leads to the acidification of soils, thus leading to a decline in their fertility and favoring the proliferation of aphids [11]. It is therefore necessary to develop an environmentally-friendly fertilization system.

In addition, harvest losses due to the main cotton pests vary from 40% to 70% of total production [12]. Four groups of pests damage the cotton plant: bollworms, defoliating caterpillars, mites and sucking insects [13]. The aphid *Aphis gossypii* is one of the sucking insects most frequently encountered on cotton [14]. *A. gossypii* causes, by drawing sap, the deformation of the foliage while producing honeydew on which sooty mold develops; it transmits around fifty viruses [15]. The intensive use of chemical insecticides has led to the development of the phenomenon of resistance in pest populations. Again, chemical pesticides have harmful effects on human health and the environment [4]. It is therefore important to develop alternative crop protection strategies for cotton.

Climate change is a major problem for agriculture in many parts of the world. In most cotton-producing countries in Africa, the crop is essentially rain-fed, therefore dependent on rainfall hazards. The late onset of rains in recent years requires increasingly late sowing. The analysis of this constraint revealed that the losses incurred by cotton farmers are very high [16]. The development of a production system that would allow the cotton plant to resist water stress is then necessary.

In regard to all these problems, it is urgent to consider the use of alternative products for cotton cultivation. In this perspective, rapeseed oil based insecticides and the rhizobacterium *B. amyloliquefaciens* FZB 42 can be considered.

This article is a literature review which summarizes the constraints linked to cotton production in sub-Saharan Africa and highlights the potential of rapeseed oil emulsion and that of the rhizobacterium *B. amyloliquefaciens* FZB 42 for cotton production.

2. Main constraints linked to cotton production

2.1. Abiotic constraints

Temperature is the main factor influencing the morphogenesis of cotton organs. According to Parry [17], the minimum growth temperature is 13°C and the optimum temperature is between 27°C and 32°C. The optimal seed germination temperature is around 30°C. The favorable environment for cotton cultivation varies between 25°C and 30°C for daytime temperatures and between 15°C and 20°C for nighttime temperatures [17].

Water requirements vary depending on the stage of development; they increase with the growth of the plant and are higher when the cotton plant develops (bearing of flower buds and flowers and formation of bolls). According to Parry [17], sunshine is a primary factor in crop development and relative humidity requirement is less than 90%. The cotton plant prefers homogeneous, deep, permeable soils rich in mineral elements. Climate change, with increasingly high temperatures, is a major problem for agriculture in many parts of the world [16]. The effects of water deficiency on the plant are both direct and indirect, because the water status of the soil interacts with the soil temperature, the availability of nutrients, in particular nitrogen [18], the development of pathogenic organisms and parasites [19]. The final yield due to a water deficiency depends on its effects on different stages of the crop development. In most cotton-producing countries in Africa, this crop is essentially rain-fed, therefore dependent on rainfall hazards. The late onset of rains in recent years has required increasingly late sowing. The analysis of this constraint revealed that the losses incurred by cotton farmers are very high [20].

2.2. Management of soil fertility and impact of nitrogen fertilization on aphids

In most cotton-producing countries in West Africa, the most used practices on farms are: crop rotation, mulching and the addition of mineral fertilizers [21]. According to Igue [22], to restore soil, farmers must adopt sustainable, low-input production systems. In this context, several cultivation systems have been

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suggested; these include the practice of mulch, the use of organic materials such as manure, compost, harvest residues, etc. However, these practices face worrying constraints at the farmer level.

The continued decline in seed cotton yield can be explained by the decline in soil fertility, the irregularities of rainfall due to climate change. The soil fertility in cotton-growing areas has been declining mainly due to the gradual decrease in the level of organic matter [23]. Indeed, the sustainability of cropping systems is based on the rational management of soil fertility [24]. Unfortunately, in the West African sub-region, cotton fertilization programs are almost exclusively mineral and recommend the annual use of approximately 200 kg/ha of NPKSMgB fertilizer. The intensive use of mineral fertilizers leads to the acidification of soils, thus leading to a decline in their fertility. In addition, the sale prices of these fertilizers are exorbitant. These fertilization programs, in addition to being expensive, promote the proliferation of aphids due to the increase in the nitrogen content of the plants that they induce. A high nitrogen concentration in plants accelerates the proliferation of aphids [25, 26]. According to Mattson [27], the development and proliferation of aphids are strictly correlated with the concentration of nitrogen in plant tissues. The positive effects of nitrogen fertilization on insect proliferation are linked to increased plant growth and particularly higher nitrogen concentrations in the leaves [28]. Nitrogen fertilization of soils contributes to the proliferation of phytophagous insects therefore [29, 30].

Aphids are sap-sucking insects that they often draw from phloem which contains higher amounts of nitrogen than other plant tissues [31]. According to Van Emden [32], high levels of soluble nitrogen in the phloem of plants provide aphids with high-quality food which can support their survival, growth and reproduction. Therefore, by increasing nitrogen concentrations in the sap, nitrogen fertilization stimulates the growth of aphids [25].

Faced with all these constraints, it is necessary to develop a fertilization system that would reduce the vulnerability of plants to these insect pests.

2.3. Main cotton pests in Sub-saharan Africa

The main cotton pests can be classified as follows:

- Defoliating caterpillars such as *Spodoptera littoralis*, *Syllepte (Sylepta) derogata*, *Anomis flava* and flea beetles (*Nisotra spp.*, *Podagrica spp.*). Cauquil [33] estimates that the most significant foliar damage is attributable to these leaf-feeding caterpillars which can cause spectacular defoliation.
- Insect Pests of the reproductive system (flower buds, flowers and bolls). These are mainly insects such as *Helicoverpa armigera, Diparopsis watersi, Earias biplaga, Earias insulana, Pectinophora gossypiella, Cryptophlebia leucotreta, Helopeltis schoutedeni and Dysdercus völkeri* [34, 35].
- Mites: *Polyphagotarsonemus latus*, is prevalent in wooded savannah regions where rainfall exceeds 1000 to 1200 mm [35].
- Sucking insects: these are jassids (*Jacobiella fascialis*), whiteflies (*Bemisia tabaci*), aphids (*Aphis gossypii*) and mealybugs (*Ferrisia virgata*). *A. gossypii* is the most harmful sucking insect on cotton [14].

2.3.1. Specificity of Aphis gossypii

A. gossypii is a polyphagous pest and very widespread in all warm regions of the world. This pest has become economically important in cotton growing areas in West and Central Africa [35]. This insect has a bisexual and parthenogenetic mode of reproduction, resulting in very rapid proliferation [36]. Aphids form dense colonies on the leaves and sometimes on the stems of host plants. They are found on cotton plants at the beginning of the cycle on young seedlings, then at the end of the cycle on old cotton plants when the bolls open [37]. The aphid feeds on the sap and injects toxic saliva in the plant; the aphid's toxic saliva causes the foliage to deform [38, 39]. This aphid transmits around fifty viruses to the plants [15]. This biting-sucking pest also plays a role in the depreciation of fiber quality as a result of deposits of sugary excrement on white cotton, causing the phenomenon of “sticky cotton” with the presence of blackish sooty mold found at the end of the cycle. Sticky cotton is depreciated on sale and this phenomenon seriously disrupts the international market and worries all players in the cotton sector [1, 35, 40].

3. Chemical control and its consequences

Before the Second World War, chemical control of aphids was limited to the application of insecticides

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based on arsenic or nicotine. Sprayed on crops, they kill the aphids that come into contact with these plants, but they have neither residual nor systemic effects. After the 1940s, chemical control enjoyed great success thanks to the use of DDT and other organochlorine compounds such as lindane. Although these insecticides have the advantage of being persistent, they also have the disadvantage of not having systemic properties [39, 41]. The persistence of residues of these products causes their accumulation in the food chain, and since this phenomenon has become known, the application of these products is no longer justified and they have been banned. The development of systemic pesticides, such as organophosphate compounds, offers new perspectives in the fight against aphids and the viruses associated with them. Later, organic chemistry offered enormous possibilities, such as the development of synthetic pyrethroids. All of these products played an important role in controlling aphid damage and disease. However, these chemical insecticides cause ecosystem imbalances because they accumulate in soil, water and air, and kill non-target organisms [39].

4. Rhizobacteria of the genus *Bacillus spp.*

Bacteria are found in the soil at an average of $6x10^8$ CFU/g. With a live weight of around 10,000 kg/ha, bacteria represent the most frequent microorganisms in soil samples [42]. Among the bacteria of the rhizosphere there is a particular group of bacteria, the rhizobacteria. Rhizobacteria are microorganisms that colonize the roots (the rhizome) of certain plants by forming symbiotic relationships with them. These rhizobacteria are able to multiply and compete with other microorganisms to occupy this area which is rich in nutrients [43]. The bacterial species most frequently isolated from soil samples belong to the genus *Bacillus* [42].

In 1897, a rhizobacteriological biofertilizer was marketed under the name 'Alinit' by the German company Bayer AG for the inoculation of cereals. This product was composed of the spores of a bacterium known today as *Bacillus subtilis.* The use of Alinit resulted in a 40% increase in grain yield. In the mid-1990s, *Bacillus subtilis* was widely used in the United States for seed treatment on more than 2 million hectares [44]. *B. subtilis* FZB24® has been marketed in Germany since 1999 and is used mainly for the treatment of potato seeds. *B. subtilis* FZB24® establishes itself temporarily in the rhizosphere of the cultivated plant. Numerous studies have described the mechanisms of beneficial action of this strain on the cultivated plant [42,45].

4.1. Beneficial effects of Rhizobacteria of the genus Bacillus spp.

Various studies have demonstrated the beneficial effects of species of the *Bacillus* genus [42,45-48], these include:

- Production of phytohormones: Hormones such as auxin, gibberellin and cytokinin can be produced by some species of *Bacillus spp*., thereby activating plant growth.
- Fixation of atmospheric nitrogen: some species of *Bacillus* are able to fix atmospheric nitrogen and transform it into organic nitrogen.
- Increase in the bioavailability of essential elements: for example, the solubilization of phosphates which can then be absorbed by the plant.
- Competitive colonization: the genus *Bacillus spp*. can colonize the rhizosphere, preventing pathogenic microorganisms from infecting the plant.
- Antagonism: by the production of anti-microbial molecules.
- Induction of immunity: some *Bacillus spp*. stimulate the immune system of plants and give them resistance against pathogenic viruses, fungi and bacteria.
- Stimulation of the natural defenses of plants by activation of their defense genes; this could be demonstrated both by molecular biology techniques and by phytopathological tests.
- Promotion of plant and root growth. In vitro, it was possible to observe, under the effect of *B. subtilis*, the formation of substances and mixtures of substances having an action similar to that of cytokinin or auxin. That is to say, the increase in the volume and ramifications of the root system modifies the endogenous phytohormonal balance of plants. Indeed, the more developed root apparatus allows better absorption of water and nutrients, and consequently, faster growth and

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greater tolerance to water stress. Basically, the stimulation of growth allows a "disease escape" of the plant: the plant can grow more quickly and manages to escape attacks from phytopathogenic microorganisms.

4.2. Summary of works carried out on Rhizobacteria of the genus Bacillus spp. for crop production

In Tajikistan, work carried out by Yao et al. [49], on the cotton plant, revealed that the inoculation of cotton seeds with *B. subtilis* FZB 24® made it possible to obtain a yield similar to that obtained with complete mineral fertilization. Furthermore, in Germany, tests carried out on around a hundred hectares revealed that the inoculation of potato seeds with this strain of *Bacillus* showed an increase in productivity similar to that observed with an addition of around 40-60 kg of nitrogen. *B. subtilis* FZB24® is harmless to animals and humans and is approved in Germany for the biofertilization of potatoes and other crops. According to Kloepper et al. [46] and Araujo et al. [50], *Bacillus amyloliquefaciens* FZB 42 and *Bacillus subtilis* FZB 24 have the same effects on plants.

Work carried out with the rhizobacterium *Bacillus amyloliquefaciens* FZB 42 in different regions of China revealed the following [51]:

- In Tibet, the use of *B. amyloliquefaciens* FZB 42 on the culture of *Coleus scutellarioides* in 2010 made it possible to increase flower formation and germination efficiency;
- In Yunnan, work on potatoes and rapeseed revealed an increase in yield of around 14% for each crop after application of FZB 42;
- In Beijing, work was carried out with FZB 42 on the cultivation of soybeans and corn. The results showed an increase in the number of pods and grains per plant and in soybean yield.

In Egypt, the impact of soaking seeds in PGPR FZB 42 combined with 39 kg/ha of nitrogen was compared with a treatment of 79 kg/ha of nitrogen on the growth and yield of cotton in agronomic trials by Monir et al. [52]. The combination of rhizobacterium with the reduced dosage of mineral fertilizer resulted in significantly more plant growth compared to mineral fertilization alone. The combination of rhizobacterium with the reduced dosage of mineral fertilizers also made it possible to obtain a seed cotton yield similar to that of full mineral fertilization. A 75% increase in yield was observed with the combination of FZB42 with 39 kg/ha of nitrogen showing the beneficial effect of the rhizobacterium on reduced mineral manure. The combination of the rhizobacterium with the full dosage of nitrogen caused a yield increase of 30%.

In a study aimed at comparing the effect of *B. amyloliquefaciens* with that of compost in an organic cotton production system in Benin, an increase in seed cotton yield of around 39% in plants treated with *B . amyloliquefaciens* FZB 42 has been observed [53]. Which means that *Bacillus amyloliquefaciens* is a rhizobacterium that is also effective in organic farming.

The effect of mineral and rhizobacteriological fertilizations on the dynamics of the populations of *A. gossypii* was determined by comparing the 3 following variants: soaking of seeds in the suspension of the rhizobacterium *B. amyloliquefaciens* FZB42, application of NPKSMgB, and the control (without fertilizer). The results showed that cotton plants treated with the rhizobacterium attracted significantly fewer aphids than those fertilized with mineral fertilizer [54, 55]. Furthermore, the effect of rhizobacterium combined with reduced dosage of mineral fertilizers on cotton growth and seed cotton yield was studied in different agro-ecological regions, and the density of major pests was assessed. Cotton plants treated with the rhizobacterium and then fertilized with 40% or 50% of the recommended fertilizer dosage gave a seed cotton yield similar to that of plants having received the full dosage of fertilizer [56]. The growth and development of cotton plants treated or not with the rhizobacterium were studied under water stress conditions, in a controlled environment. The results showed that whatever the environmental conditions, seeds treated with the rhizobacterium *B. amyloliquefaciens* FZB42 germinated abundantly and faster than untreated seeds. In addition, these seeds gave rise to seedlings that developed more quickly than those of the control (untreated) [56].

5. Rapeseed oil based insecticide

Rapeseed oil is a vegetable oil that is obtained by crushing rape seeds. Indeed, rapeseed (*Brassica oleracea L., 1753*) is an oilseed herbaceous plant, resulting from the hybridization of a variety of cabbage (*Brassica oleracea*) and turnip (*Brassica*

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campestris). Etymologically, rapeseed comes from the Dutch coolzaad (meaning cabbage seed). Rapeseed is an annual plant with yellow flowers from the cruciferous family (*Brassicaceae*). The insecticidal effect of rapeseed oil against aphid species is known, and the product is said to act by contact since the aphids die by asphyxiation [57, 58].

There are rapeseed oil-based insecticide formulations on the european market used to control aphids [57]. Unfortunately, these formulations are expensive despite the low cost of the canola oil itself. We must therefore find a way to allow small African producers to exploit the insecticidal potential of this oil. Consequently, work was carried out to assess the potential of the rapeseed oil emulsion prepared by hand. To this end, the population dynamics of *Aphis gossypii* were studied following the application of rapeseed oil at different concentrations on plants subject to natural infestation. The results showed that in the experimental station, concentrations of 2% to 4% of rapeseed oil emulsion significantly reduced the density of aphid populations. Additionally, in somewhat field conditions, the number of plants attacked by aphids was significantly reduced, 3 days after application of the rapeseed oil emulsion at concentrations of 2% and 3% [59].

6. Conclusions

In view of the encouraging data presented in this review, it can be concluded that the rhizobacterium *B. amyloliquefaciens* FZB42 and rapeseed oil based insecticides can be integrated into the cotton production system, respectively for plant fertilization and integrated management of sucking pests.

Authors' contributions

Wrote the majority of the sections on pests constraints and management, A.Z.A.; Wrote the remaining portions of the article, TBCA.

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Conflicts of interest

The authors declare no conflict of interest

References

1. Celini, L. Le Puceron du cotonnier: *Aphis gossypii* (Glover) et son parasite *Aphelinus gossypii* Timberlake en République centrafricaine, Insect 2001, n° 122-2001(3), 6- 10. https://www.researchgate.net/publication/309348311_
2. Ton, P. La production cotonnière et conditions de vie en milieu rural en Afrique de l'Ouest. Oxfam-GB et ENDA 2001, 88p. http://enda-cremed.org/bpd/opac_css/index.php?lvl=notice_display&id=6119.
3. Martin, T. La résistance aux insecticides de *Helicoverpa armigera* (Hübner) en Afrique, de l'Ouest: du mécanisme à la gestion. Thèse de Doctorat de l'Université Toulouse III, discipline chimie. 2003, pp:1-80. https://agritrop.cirad.fr/516382.
4. Martin, T.; Ochou G.; Hala-N'klo F.; Vassal, J.M.; Vaissayre, M. Pyrethroïd resistance in the cotton bollworm, *Helicoverpa armigera* (Hubner) in west Africa. Pest management. Science 2000, 56(6), 549-554. 10.1002/(SICI)1526-4998(200006)56:6<549::AID-PS160> 3.0.CO;2-Y.
5. Hougni, A. Qualités et valorisation du coton-fibre d'Afrique Zone Franc (AZF) dans les échanges internationaux. Thèse de doctorat ès sciences économiques, Université de Bourgogne, Bourgogne, 2009, p.330. https://agritrop.cirad.fr/562523.
6. Kpadé, P.C. Adaptation de la coordination et nouvelles contradictions entre acteurs du système coton au Bénin face à la libéralisation économique. Thèse de Doctorat Unique, Université de Bourgogne, 2011, 371p. https://theses.hal.science/tel-00741138/document
7. Ton, P.; Wankpo, E. La production du coton au Bénin: projet d'analyse d'une spéculation agricole par pays-FIPA, Pays Bas, 2004, 52p. https://hubrural.org/Benin-La-production-du-coton-au.html?lang=en
8. Dègla, K.P. Rentabilité économique et financière des exploitations cotonnières basées sur la Gestion Intégrée de la Fertilité des Sols et des Ravageurs au Nord-Bénin. Bulletin de la Recherche Agronomique du Bénin(BRAB), Numéro spécial Coton. 2012, ISSN: 1025-2355. 26-35. http://www.slire.net/document/1746.
9. Sylvie, P.; Martin, J.; Debru, J.; Vaissayre, M. Le coton biologique au Paraguay .2. Production et contraintes

agronomiques. Biotechnol. Agron. Soc. Environ. 2010, 14(2), 311-320. https://www.researchgate.net/publication/44260989.

10. Allagbe, C.M.; Adegbola, P.Y.; Ahoyo, A.N.R.; Ahihou, C. M. K.; Crinot, G.F. D. J. C. E., Hessavi, P.M.; Djenontin, A.J. Mensah, G.A. Evaluation socio-économique des systèmes de cultures à base de cotonculture au Bénin. Rapport Technique d'exécution. 2014, Dépôt légal N° 7516 du 15 octobre 2014, 4ème trimestre, Bibliothèque Nationale (BN) du Bénin. ISBN: 978-99919-0-138-1 44p. http://www.slire.net/document/2201?locale=fr.
11. IFDC. Projet "Amélioration de la compétitivité du secteur coton à partir des zones pilotes de Banikoara et de Dassa-Zoumè - Bénin", Ambassade du royaume des Pays-Bas, Bénin. 2009, 50p. https://docplayer.fr/56367966-Projet-amelioration-de-la-competitivite-du-secteur-coton-a-partir-des-zones-pilotes-de-banikoara-et-de-dassa-zoume-benin.html.
12. Levrat, R. Le coton dans la zone franc depuis 1950, un succès remis en cause, Paris, Ed Harmattan. 2009, 256p. https://www.editions-harmattan.fr/livre le_coton_ dans_la_zone_franc_depuis_1950_un_succes_remis _en_cause_regine_levrat-9782296078857-27840.html.
13. Vaissayre, M; Deguine, J.P. Cotton protection programmes in francophone Africa. Phytoma. 1996, 489, 26–35. https://publications.cirad.fr/une_notice.php? Dk =388653.
14. Vaissayre, M. Quelques données sur les insectes producteurs de miellats et les méthodes de gestion de leurs populations. Actes du séminaire, 4–7 juillet 2001, Lille, France, CFC/ICAC 11 Technical report. 2001, 3p. https://agritrop.cirad.fr/489329/
15. Appert, J.; Deuse, J. Les ravageurs des cultures vivrières et maraîchères sous les tropiques. Edition Maisonneuve et Larose. Paris, France. 1982, ISBN: 2-7068-0814-4-137-138. https://ulysse.univ-lorraine.fr/discovery/fulldisplay/alma991003550297055596/33UDL_INST:UDL.
16. Lobell, D.B., Gourdji, S.M. The influence of climate change on global crop productivity. Plant Physiology 2012, 160:1686–1697. https://doi.org/10.1104/pp.112.208298.
17. Parry, G. Le cotonnier et ses produits. G-P. Maisonneuve & Larose, Paris (Ve). 1982, 502p. https://agritrop.cirad.fr/381534/
18. Radin, J.W.; Mauney, J.R., Guinn, G. Effects of N fertility on plant water relations and stomatal responses to water stress in irrigated cotton. Crop Sci. 1985, 25(1), 110-114. https://plantstomata.wordpress.com/tag/radin-j -w/
19. Ragazzi, A. Infection of cotton by *Fusarium oxysporum f.*sp.*vasinfectu*m as affected by water stress (summary). Phytoparasitica. 1995, 23(4), 315-321. https://doi.org/10.1007/BF02981424.
20. Passioura, J.B. Accountability, philosophy and plant physiology. SEARCH. 1979, 10 (10): 347-359. https://www.researchgate.net/publication/285484017.
21. Haan, L.J. Agriculteurs et éleveurs au Nord du Bénin. Ecologie et genres de vie. Paris-France. 1997, pp67-91 http://hdl.handle.net/1887/4792.
22. Igue, A.M.; Saidou, A.; Adjanohoun, A.; Ezui, G.; Attiogbe, P.; Kpagbin, G.; Gotoechan-Hodonou, H.; Youl, S.; Pare, T.; Balogoun, I.; Ouedraogo, J.; Dossa, E.; Mando, A.; Sogbedji, J.M. Evaluation de la fertilité des sols au sud et centre du Bénin. Bulletin de la Recherche Agronomique du Bénin (BRAB) Numéro spécial. 2013, ISSN: 1840-7099. http://www.slire.net/download/1798/igue_et_al._evaluation_fertilit.pdf.
23. Djenontin, A.J.; Dagbenonbakin, G.; Igue, A.M.; Azontonde. A.; Mensah, G.A. Pratiques endogènes de valorisation des résidus de récolte dans la gestion de la fertilité des sols des exploitations agricoles au Nord du Bénin. Dépôt légal N° 5568 du 09/01/ 2012, 1er trimestre 2012, bibliothèque Nationale (BN) du Bénin ISBN: 978-99919-978-0-3. 2012, 9p. https://doi.org/10.13140/RG.2.1.5143.1760.
24. Igué, A.M.; Agossou, A.; Ogouvidé, F.T. Influence des systèmes d'exploitation agricole sur l'intensité de la dégradation des terres dans le département des Collines au Bénin. Bulletin de la Recherche Agronomique. 2008, (61), 39-51. http://www.slire.net/download/750/article6_brab61_igu_et_al_influence-syst_mes-exploitation_agricole-intensit_-d_gradation-terres.pdf.
25. Maltais, J.B. The nitrogen content of differnt varieties of peas as a factor affecting infestations by *Macrosiphum pisi* (Kltb.) (Homoptera: Aphididae). A preliminary report. The Canadian Entomologist. 1951, 83(02), 29-33. https://doi.org/10.4039/Ent8329-2.
26. Strong, D.R.; Lawton, J.H.; Southwood, R. Insect of plant community pattern and mechanisms. Black well scientific publications, Oxford. 1984, 313. https://catalogue.nla.gov.au/catalog/2321604.
27. Mattson, W.J. Herbivory in relation to plant nitrogen content. Ann. Rev. Ecol. Syst. 1980, 11, 119-161. https://doi.org/10.1146/annurev.es.11.110180.001003.
28. Waring, G.L.; Cobb, N.S. The impact of plant stress on herbivore population dynamics. In: Insect-plant interactions, Vol. IV. Edited by E.A. Bernays. CRC Press, Florida. 1992, 167-226.
29. Meriç, K. Études sur les composés polyphénoliques en relation avec l'alimentation de la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* (Clem.) Thèse de Doctorat en Sciences forestières à l'Université

Laval/ Faculté de foresterie et de géomantique. 2005, 175p. https://corpus.ulaval.ca/server/api/core/bitstreams/f9b853c7-3cf5-4703-bc04-6ecf443fa1de/content

30. Staley, J.T.; Stewart-Jones, A.; Pope, T.W.; Wright, D.J.; Leather, S.R.; Hadley, P.; Rossiter, J.T.; Van Emden, H. F.; Poppy, G. Varying responses of insect herbivores to altered plant chemistry under organic and conventional treatments. Proceedings of the Royal Society B-Biological Sciences. 2010, 277, 779-786. https://doi.org/10.1098/rspb.2009.1631.
31. Klingauf, F.A. Feeding, adaptation and excretion. In: Minks A. K. and P. harrowing (Editor). Aphids their biology, natural enemies and control. Elsevier science publishers. New-York (2). 1987, 225-253. https://books.google.bj/books/about/Aphids.html?id=mgHxAAAAMAAJ&redir_esc=y
32. Van Emden, H.F. Studies on the relations of insect and host plant.III. A comparison of the reproduction of *Brevicogme brassicae* and *Mysus persicae*: (Hemiptra: Aphididae) on brussels sprout plants supplied with different rates of nitrogen and potassium. *Entomologia Experimentalis et Applicata*. 1966, 9(4), 444-460. https://doi.org/10.1111/j.1570-7458.1966.tb01005.x
33. Cauquil, J. Maladies et ravageurs du cotonnier en Afrique au sud du Sahara. 1986, 92p https://www.sidalc.net/search/Search/Versions?id=dig-cirad-fr-445286&keys%5B0%5D=AT%20cauquiljean%20maladiesetravageursducotonnierenafriqueausuddusahara
34. Cauquil, J. Nouveaux devéloppements dans la protection contre les ravageurs en Afrique francophone au sud du Sahara.Coton et Fibres Tropicales. 1990, 65 (1), 45-48. https://agritrop.cirad.fr/429845/
35. Cauquil, J. Maladies et ravageurs du cotonnier en Afrique au sud du Sahara. 2ème édition, 1993, 92p. https://agritrop.cirad.fr/301827/
36. Lambert L. Les pucerons dans les légumes de serres: Des bêtes de sève. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation. 2005. https://www.agrireseau.net/legumesdeserre/documents/69864/ les-pucerons-des-betes-de-seve.
37. Dixon, A.F.G. The distribution of Aphid infestation in relation in the demography of plant parts. American Naturalist. 1986, 127: 410-413. https://doi.org/10.1086/284492.
38. Josephyne, P. Différenciation génétique et écologique des populations du puceron *Brachycaudus helichrysi* (Hemiptera: Aphididae): mise en évidence de deux espèces soeurs aux cycles de vie contrastés. Thèse de doctorat. Ecole Doctorale: Systèmes Intégrés en Biologie, Agronomie, Géosciences, Hydrosci. Env. SIBAGHE. Montpellier (France). 2012, 255p.
39. Alavo, T.B.C. Investigation on the entomologenic fungus *Verticillium lecanili* (Zimm) *Viegas* (Hyphomycets: moniliceae) for the biological of aphids (Homoptera: Aphididae): ISBN 3-8957-394-1, edition verlag Dr Köster, Berlin. 2000, 101p.
40. Deguine, J.P., Ferron P. Protection des cultures et développement durable bilan et perspectives. Courrier de l'environnement de l'Institut National de la Recherche Agricole. 2004, n°52.
41. Yarou, B.B. Potentialités du kaolin et d'un nouveau régulateur de croissance (Méthoxyfenozide) pour la lute intégrée contre les Aphides (Homoptera: Aphididae) et *Hélicoverpa armigera* (Lepidoptera: Noctuidae). Mémoire de Master en Entomologie Appliquée. Université d'Abomey-Calavi, Bénin. 2008, 26p. https://www.memoireonline.com/11/13/7726/m_Potentialites-du-kaolin-et-d-un-nouveau-regulateur-de-croissance--Methoxyfenozide--pour-la-lut0.html
42. Kilian, M.; Steiner, U.; Krebs, B.; Junge, H.; Schmiedeknecht, G.; Hain, R**.** FZB24® *Bacillus subtilis* – mode of action of a microbial agent enhancing plant vitality. Pflanzenschutz-Nachrichten Bayer 1/00. 2000, 1, 72–93.
43. Beauchamp, C.J. Mode d'action des rhizobactéries favorisant la croissance des plantes et potentiel de leur utilisation comme agent de lutte biologique. Phytoprotection. 1993, 74, 19-27. https://doi.org/10.7202/706033AR.
44. Backman, P.A., Brannen, P.M.; Mahaffe, W.F. Plant response and disease control following seed inoculation with *Bacillus subtilis*. In: Improving plant productivity with Rhisospere Bacteria. 1994, Ryder M. H. *et al*. (eds.), Division of soils, Glen Osmond. https://catalogue.nla.gov.au/catalog/191090.
45. Krebs, B.; Hoding, B.; Kubart, S.; Alemayehu, M.; Junge, H.; Schmiedeknecht, G.; Grosch, R.; Bochow, H.; Hevesi, M. Use of *Bacillus subtilis* as biocontrol agent. I. activities and caraterization of *Bacillus subtilis strains*. Z. pflanzenkh. Pflanzenshutz. 1998, 105, 181-197.
46. Kloepper, J.W.; Ryu, C.M.; Zhang, S. Induced systemic resistance and promotion of plant growth by *Bacillus* spp. Phytopath. 2004, 94, 1259-1266**.** https://doi.org/10.1094/PHYTO.2004.94.11.1259.
47. Idriss, E.E.; Iglesias, D.J.; Talon, M.; Borriss, R. Tryptophan-dependent production of indole-3-acetic acid (IAA) affects level of plant growth promotion by *Bacillus amyloliquefaciens* FZB42. Molecular Plant-Microb. Interact. 2007, 20, 619-626. https://doi.org/10.1094/MPMI-20-6-0619.
48. Schönbeck, F.U.; Steiner, T.K. Induced resistance: Criteria, mechanisms, practical applications and estimation. Z. PflKrankh. Pflan- zenschutz. 1993, 100,

https://doi.org/10.58985/jafsb.2024.v02i03.53

541–557.

49. Yao, A.V.; Bochow, H.; Karimov, S.; Boturov, U.; Sanginboy, S.; Sharipov, A.K. Effect of FZB 24® *Bacillus subtilis* as biofertilizer on cotton yields in field tests. Arch. Phytopathol. Plant Pathol. 2006, 39(4), 323-328. https://doi.org/10.1080/03235400600655347.
50. Araujo, F.; Henning, A.; Et Hungria, M. Phytohormones and antibiotics produced by *Bacillus subtilis* and their effects on seed pathogenic fungi and on soybean root development. World J. Microbial. Biotechnol. 2005, 21, 1639-1645. https://doi.org/10.1007/s11274-005-3621-x.
51. ABiTEP GmbH. Application experiments. 2011. http://www.chinapgp.net/content/pdf/ applicat ion_ experiments/ae_luofeng_08.pdf.
52. Monir, M.E.H.; Bochow, H.; Junge, H. The biofertilising effect of seed dressing with PGPR *Bacillus amyloliquefasciens* FZB 42 combined with two levels of mineral fertilizing in African cotton production. Arch. Phytopathol. Plant Protect. 2012, 45 (19), 1-11 https://doi.org/10.1080/03235408.2012.673259.
53. Alavo, T.B.C.; Boukari, S.; Fayalo, D.G.; Bochow, H. Cotton fertilization using PGPR *Bacillus amyloliquefaciens* FZB42 and compost: Impact on insect density and cotton yield in North Benin. West Afr. Cogent. Food Agric. 2015, 1, 1063829. https://doi.org/10.1080/23311932.2015.1063829.
54. Fayalo, G.D.; Aouco, A.; Alavo, T.B.C. Dynamique des populations du puceron *Aphis gossypii (*Homoptera: Aphididae) sur le cotonnier en conditions de fertilisation minérale et rhizobacteriologique. Tropicultura. 2016, 34(1), 1-7. https://doi.org/10.1017/S1742758400018725.
55. Aouco, A.; Fayalo, G.D.; Alavo, T.B.C., Bochow, H. Seed dressing using plant growth-promoting Rhizobacteria *Bacillus amyloliquefaciens* FZB42 Reduces Aphid's proliferation in cotton. In: tropentag proceedings. 2015, International research on food security, Natural Resources Management and Rural Developement. Crop biotic stresses (DPG session). 16-18 Sept.2015. Berlin-Germany. https://www.tropentag.de/2015/proceedings/proceedings.pdf.
56. Alavo, T.B.C.; Aboudou, M.; Didolanvi, M.; Fayalo, D.G. Effets de la rhizobactérie *Bacillus amyloliquefaciens* FZB 42 sur la tolérance au stress hydrique et le rendement du cotonnier. International journal of biological and chemical sciences. 2018, 12(3), 1437-1446. https://doi.org/10.4314/ijbcs.v12i3.29.
57. Stanislav, T.; Dragan, Z.; Nevenka, V. Field efficacy of three insecticides against cabbage stink bugs (Heteroptera: Pentatomidae) on two cultivars of white cabbage. Pest management Sc. 2006, 52(2), 79-87. https://doi.org/10.1080/09670870600568212.
58. Alavo, T.B.C.; Mensah, D.K. Effet de l'émulsion d'huile de colza sur le puceron Aphis craccivora pour la protection intégrée du niébé (vigna unguiculata). Annales des Sciences Agronomiques. 2015, 19(1), 43-51.
59. Fayalo, G.D.; Sokenou, F.F.D.; Abdou, M.; Alavo, T.B.C. Effet de l'huile de colza sur les populations du puceron *Aphis gossypii* pour la protection du cotonnier. Int. J. Biol. Chem. Sci. 2014, 8 (6), 2508-2515. https://doi.org/10.4314/ijbcs.v8i6.13.

https://doi.org/10.58985/jafsb.2024.v02i03.53