IPM to Control Soil-Borne Pests on Wheat and Sustainable Food Production

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Abstract

Dababat, A.A., G. Erginbas-Orakci, F. Toumi, H.-J. Braun, A. Morgounov and R.A. Sikora. 2018. IPM to Control Soil-Borne Pests on Wheat and Sustainable Food Production. Arab Journal of Plant Protection, 36(1): 37-44.

Soil Borne Pathogens (SBPs) including the *Heterodera* species, cereal cyst nematode (CCN), *Pratylenchus* species, root lesion nematode and crown rot (CR) caused by Fusarium species, attack the roots of cereal crops resulting in a high yield loss and reduced grain quality and quantity. The damage caused by these diseases is accelerated in areas where water stress and monoculture practices dominate. Sustainable agriculture production of rain-fed crop exposed to drought, especially those growing under arid and semi-arid conditions, is being impacted by climate change due to hotter and drier soils. It is important to recognize that a plant's ability to secure adequate amounts of water is severely impacted by the destabilizing effects of nematodes and root rotting fungi on root architecture. Integrated crop health management approaches, using both modern cultivars with resistance/tolerance to these organisms, as well as, technologies that stimulate root health and growth coupled with modern nematode management strategies such as chemical, biological and cultural are needed for sustainable production in the ever-drier environments that are now a reality in many areas of the world. Resistance is environmentally friendly and biologically effective once identified. However, resistance has only been identified against one of the CCN species found in Turkey; *Heterodera filipjevi*. This resistance is not yet present in the varieties widely grown in the region. Therefore, alternative approaches to limit the damage caused by SBPs are needed. Extensive screening of wheat germplasm against SBPs has identified many moderately resistant germplasm in winter and spring wheat germplasm. However, CR remains a significant bottleneck in many wheat-growing areas around the world. Hundreds of wheat lines are screened annually for SBP at CIMMYT Turkey in collaboration with the Grains Research Development Corporation and many new moderately resistant to resistant lines have been identified. A number of these sources of resistance are new and previously unreported QTL's have been identified through association mapping. The new sources of resistance to the SBPs that may be useful for selecting parents and deploying resistance into elite germplasm adapted to regions where it is a problem. Nematologists, breeders and agronomists need to work together to find solution to the complex issues facing agricultural production and use multidisciplinary approaches to move forward in insuring food security for all. Recent research within the SBP program of the International Maize and Wheat Improvement Center (CIMMYT) has focused on germplasm screening, the potential of this germplasm as source of resistance, and how to incorporate the new sources of resistance into breeding programs. Breeding for resistance is particularly complicated and difficult when different species and pathotypes coexist in nature. Other current and future research will address the use of endophytic microorganisms and other cultural practices to the yield losses incurred by SBPs. There is currently insufficient breeding for resistance to SBPs due to a lack of expertise and recognition of SBPs as a factor limiting wheat production potential, inappropriate breeding strategies, slow screening processes, and increased research funding is required for a more holistic approach to plant health management.

Introduction

The soil is a favourable habitat for a multitude of microorganisms including bacteria, fungi, algae, and protozoa and many macro-organisms. Soil contains massive numbers of microorganisms estimated between one and ten million per g of soil – with bacteria and fungi the most prevalent. The soil also harbors a large number of macro organisms such as nematodes, helminths and insects. Some of these organisms are beneficial whereas others can infect plants. These so-called soil-borne plant pathogens or pests may complete their life cycle in the soil, or may spend part of it on the aerial parts of the plant (12, 31).

Soil-Borne Pathogens for example Crown Rot (*Fusarium* spp.; CR) (SBPs) and the plant parasitic nematodes belonging to the Cereal Cyst Nematodes (*Heterodera* spp.; CCN), Root Lesion Nematodes (*Pratylenchus* spp.; RLN) attack roots of cereal crops resulting in high yield loss and reduced grain quality. The damage caused by these diseases is accelerated in areas where water stress and monoculture practices dominate. Sustainable agriculture production of rainfed crops exposed to drought, especially those growing under arid and semi-arid conditions, is being impacted by climate change induced hotter and drier soils. It is important to recognize that a plant's ability to secure adequate amounts of water is severely impacted by the destabilizing effects of nematodes and root rotting fungi on root architecture. Integrated crop health management approaches, using both modern cultivars with resistance/tolerance to these organisms, as well as, technologies that simulate root health and growth coupled with modern nematode management strategies such as chemical, biological and cultural technologies are needed for

* This symposium was sponsored by the FAO Near East and North Africa Regional Office, and organized as part of the 12th Arab Congress of Plant Protection held in Hurghada, Egypt, 5-9 November 2017.

http://dx.doi.org/10.22268/AJPP-036.1.037044

sustainable production in the ever-drier environments that are now a reality in many areas of the world. Resistance is an environmentally friendly and biologically effective management tool once it is found. However, resistance has only been identified against one of the CCN species found in Turkey, *Heterodera filipjevi*. This resistance is not yet present in the varieties widely grown in the region. Therefore, alternative approaches to limiting the damage caused by SBPs are needed. Extensive screening of wheat germplasm against SBPs has identified many moderately resistant germplasm in winter and spring wheat germplasm. However, CR remains a significant bottleneck in many wheat-growing areas around the world. Hundreds of wheat lines and accessions are screened annually for SBP at the International Maize and Wheat Improvement Center (CIMMYT) Turkey in collaboration with the Grains Research Development Corporation (GRDC), and many new moderately resistant to resistant lines have been identified. A number of these sources of resistance are new and previously unreported QTL's and have been identified through association mapping. The new sources of resistance to the SBPs that may be useful for selecting parents and deploying resistance into elite germplasm adapted to disease impacted regions. Nematologists, pathologists, breeders and agronomists need to work together to find solutions to the complex issues facing agricultural production and use multidisciplinary approaches to move forward in ensuring food security for all. Recent research within the SBP program at CIMMYT has focused on germplasm screening, the potential of this germplasm as a source of resistance, and how to incorporate the new sources of resistance into breeding programs. Breeding for resistance is particularly complicated and difficult when different species and pathotypes coexist in nature. Other current and future research will address the use of endophytic microorganisms and other cultural practices to reduce yield losses caused by SBPs. There is currently insufficient breeding for resistance to SBPs due to a lack of expertise and recognition of SBPs as a factor limiting wheat production potential, inappropriate breeding strategies, slow screening processes. Therefore, increased research funding is required for a more holistic approach to plant health management.

Integrated Pest Management

Integrated Pest Management (IPM) means the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment via following the three main IMP components: prevention, monitoring and intervention. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms (FAO, 2017). IPM is a broad-based approach that integrates practices for economic control of pests. Efforts to increase the productivity of the land in both developed and developing countries has accelerated the development and adoption of production practices that generally intensify crop protection problems (6). The concept of pest management has now been broadened to include all classes of pests (pathogens, insects, nematodes, weeds) and in this context, is commonly referred to as IPM with the implication of both methodological and disciplinary integration (15). One or more combinations of cultural, mechanical, chemical and biological control methods are usually used in IPM strategies. Susceptible plants infested with SBPs are also more often attacked by pest insects when compared with healthy plants which normally are resistant or tolerant plants.

Soil-Borne Diseases

Microbial communities play a pivotal role in the functioning of plants by influencing their physiology and development. While many members of the rhizosphere microbiome are beneficial to plant growth, plant pathogenic microorganisms can often still infect the root system by breaking through the protective microbial shield in the rhizosphere and thereby overcome the innate plant defense mechanisms in order to cause disease (34). In fact, all soils tend to be disease suppressive to some extent; if soil-borne plant pathogens are introduced to sterilized soil, they often have greater negative effects on plants than they do in normal soils (11). Soil-borne pathogens inhabit the rhizosphere of most if not all economically important crop plants. They are very important due to their capabilities to attack and infect several of our food resources and causing severe damage in terms of yields quantitates and qualities. Several fungal pathogens (*Fusarium*, *Verticillium*, *Alternaria*, *Phytophthora*, *Didymella*, *Rhizoctonia*, *Sclerotium*, *Pythium*, and *Rhizopus*) are the most predominate and common soil inhabitant and considered the main causal organisms for the most frequent plant diseases globally (5, 11). Remarkably, some of these fungal pathogens can attack a wide range of different host plants and causing severe damage while others are very specific having very narrow host ranges. For example, more than 200 diseases were recorded on tomato plants and were considered responsible for 70 to 95% of the annual losses to tomato production while *Fusarium* wilt disease is only responsible for 10 to 50% of these losses (32). Soil-borne pathogens were responsible for an estimated 10% of losses in vegetable crops. Plant-parasitic nematodes alone are estimated to reduce production of all world crops by 10% (59) causing annual economic losses valued at over $125 billion (16). Agrios (1) reviewed global crop losses due to diseases and estimated that attainable crop production in 2002 was $1.5 Trillion. However, actual crop production was 36.5% lower than that attainable or equal to $950 Billion. Not surprisingly crop production without plant protection was less than half of that produced or only $445 Billion. This indicates that losses prevented by crop protection equalled $415 Billion. The actual annual loss to world crop production is about $550 Billion with diseases causing 14.1% or $220 Billion in crop production. The global direct and indirect crop losses due to pests and pathogens attack ranged from 20 to 40% (37, 38, 53, 54). The phrase "losses" therefore inadequately reflect the true costs of crop losses to consumers, public health, societies, environments, economic fabrics and farmers.

Moreover, the infection with SBPs led to many other negative consequences in global crop production. SBPs have prevented cultivation of some important crops in specific regions of the world. For example, SBPs prevented: 1) the growing onion in upper Egypt due to white rot disease (*Sclerotium cepivorum*), 2) the planting of some high yielding varieties of wheat due to their sensitivity to some races of wheat rust, and 3) limitation in the cultivation coffee in Sylan due to rust disease.

Soil-borne pathogens require a susceptible plant for the development of their parasitic phase, but they may persist in the soil as saprophytes on residues, or as resistant, dormant forms, from several weeks to several years, depending on their biology (31). Soil-borne pathogens pose a serious threat to global agriculture by destroying 10% of the world crop production every year. Up to 83% of soils under wheat harbor cyst nematodes CCN, 40% the root lesion nematode RLN, and 60% common root rotting (CRR) fungi.

The root rotting fungi cause yield losses above 40% on winter wheat and cereal cyst nematodes reduce yields by more than 30% every year (28, 36) in Turkey, one of the largest producer of wheat in the developing world, producing on average 20 million Mt annually on more than 9 million hectares of cultivable land. Similarly, in Australia, the 6th largest wheat producer in the world, SBPs including CR, CRR, CCN and RLN cause significant yield loss to cereal production in the order of AUD 104 x 10^6/year. Given the similarities in agronomic practice and climatic conditions between wheat producing areas in WANA (West Asia and North Africa), South America, South Africa and other parts of the world, it is likely that SBPs are causing similar economic losses (36). In the marginal cereal production areas of WANA, Australia and Canada, losses between 3-50% have been reported (23, 33, 35, 47). Nematode parasites of cereals and dryland root rots are the most economically important SBPs in regions where cereals dominate rotations and where sub-optimal growing conditions and or cultural practices are common.

The root-knot nematodes (*Meloidogyne* spp.; RKN) are the most economically important group of plant-parasitic nematodes worldwide. *Meloidogyne* is a genus formed by more than 100 species (29). *M. incognita, M. javanica, M. Hapla*, and *M. arenaria* are the most four important species affecting crop productivity around the world. The genus *Pratylenchus* is a migratory endoparasites which comprises more than 90 species with a worldwide distribution (57). The four-major species infesting small grain are; *P. crenatus*, *P. neglectus*, *P. penetrans* and *P. thornei* (43). They are among the most common plant-parasitic nematodes responsible for significant yield loses worldwide and can be considered as the 2nd most important plant-parasitic nematode after the genera *Meloidogyne*.

Dryland root rots, which include root, crown and foot rots (FR), often include a complex of fungi with several species of CR and CRR (*Bipolaris sorokiniana* (syns. *Helminthosporium sativum*), *H. sorokiniana,* Teleomorph *Cochliobolus sativus* (Ito & Kurib., Dresch. ex Dast.). Globally, *Fusarium* spp. is an economically recognized important group of fungi which include more than 100 species causing CR, FR, root rot (RR) and head blight (2, 10, 26, 40, 58). Crown rot can be caused by several *Fusarium* species including *F. pseudograminearum* (teleomorph *Gibberella coronicola*), *F. crookwellense*, *F. avenaceum* (teleomorph. *G. avenacea*), *F. culmorum*, *F. acuminatum* and *Microdochium nivale* (teleomorph *Monographella nivalis*) (17, 52). The importance of CR has increased with increasing adoption of residue retention and reduced tillage practices, which favor inoculum buildup and thereby greater levels of infection (13, 49, 60).

Crown rot is one of the most economically important diseases of cereals caused by *Fusarium* species in many rainfed wheat cropping regions of the world due to difficulties in its management as imposed by modern agriculture. Crown rot and CRR cause more than 35% losses to cereals in rain-fed (dry-land) wheat production systems throughout the world (15, 19, 24, 30, 50). The predominance of the species is mostly influenced by climatic conditions especially temperature requirements (41). In Central Anatolia Plateau of Turkey, cereal root rots contribute to significant yield losses up to 24-36% in commonly cultivated winter wheat varieties (3, 28). Root and crown rot diseases cost Australian wheat growers around USD 150 x10^6 per year from an annual production of around 20 Mt (44). *F. culmorum* infects wheat, barley, oats, clover, rye grasses, sorghum and numerous other species. In Turkey, *F. culmorum* has been described as the dominant pathogen in dryland conditions, where the climate is cold in winter with a dry summer (56).

CR is common under hot-dry conditions and the fungus colonizes stressed plants during the grain filling period (14). Crown rot causes necrosis and dry rot of the crown, the basal stems and root tissue. The key symptoms of the disease are whitehead formation (premature ripening) and a chocolate-brown lesion in the crown region of wheat (14, 18). The white heads are formed due to destruction of the vascular system by the fungus which interferes with uptake of mineral and water to the head during grain filling. The damage to spring and winter cereals is usually unnoticed until white heads appear shortly before maturity (42).

Less emphasis has been given to SBPs as a limiting factor for wheat production due to focus on more visible foliar and head diseases. Dryland CR is a serious challenge facing agriculture especially in rainfed and wheat monoculture cropping regions in the world. In rainfed wheat production system where cereal monoculture is practiced extensively as it is in Turkey, rotation offers limited option to control *F. culmorum*.

Among all SBPs, *Fusarium* species were considered the most common and predominant fungi in the rhizosphere where they can cause different plant diseases on different host plants and dramatically reduce both the quality and quantity of yield but are also known to be beneficial as mutualistic endophytes. One of these important species is *F. oxysporum lycopersici*, which was first described in England in 1895 and since that date was considered the main causal pathogen of tomato *Fusarium* wilt diseases. It can infect not only tomato plants but also many other host plants i.e. eggplant and several other weeds.

Sustainable agriculture production of rainfed crop exposed to drought, especially those growing under arid and semi-arid conditions, is being impacted by climate change induced hotter and drier soils. It is important to recognize that a plant's ability to secure adequate amounts of water is severely impacted by the destabilizing effects of plant-parasitic nematodes and root rotting fungi on root architecture. The inability of the root to expand into deeper soil horizons exasperates the effects of heat and drought on root growth and yield. The importance of plant disease control is critical especially in those countries which have a rapidly expanding of populations as the middle east and are exposed to hotter and drier climates in the future. The limitations in the number of control tools for SBPs and plant parasitic nematodes management, makes finding suitable alternative biocontrol agents for integrated management important (45).

Soil-Borne Diseases Control Options

Cultural practices for management of crown rot include delayed planting, and optimized nitrogen applications to reduce late season water stress which provide only partial control and are not reliable for limiting damage (17, 42, 49). Since options for chemical control are limited and not cost-effective, host plant resistance is the most efficient, economic and reliable approach to reducing yield losses caused by soil-borne disease at this time (20, 61). Different control options for management of SBPs include: chemicals, biological control, sowing time, other cultural practices, crop rotation, clean fallow, trapping crops, resistant germplasm, certified seeds, physical controls (4, 7, 8, 9, 21, 22, 25, 27, 31, 33, 39, 45, 46, 48, 55).

Soil-borne pathogens generally affect the root system of plants or the base of the stem, in some cases developing on upper parts of the plant through aerial dispersal from soil inoculum or via transport and/or growth in the vessels, leading to vascular diseases. Such pathogens may cause extensive damage to crops by limiting water and nutrient uptake (root necrosis) and/or transfer towards the upper parts of the plant (vascular disease), or by reducing the quality of crop products developing underground (root or tuber rot, gall, proliferation, etc.). This damage has led to the focusing of considerable effort on improving our understanding of the biology and ecology of these diseases, with the aim of developing control methods (31).

Sustainable Food Production

Food and Agriculture Organization of the United Nations (FAO) identified five key principles of sustainable food production and agriculture (http://www.fao.org/sustainability/en/):

1) Improving efficiency in the use of resources. Further gains in productivity will still be needed in the future to ensure sufficient supply of food while limiting the expansion of agricultural land and preserving natural ecosystems. However, while in the past efficiency has been mostly expressed in terms of yield (kg per hectare of production), future productivity increase will now need to consider water and energy-smart production systems to reduce emission of greenhouse gas.
2) Conservation, protection and enhancement of natural resources. While intensification has positive effects on the environment through reduced agricultural expansion, it also has potentially negative impact on the environment. The most widespread model of agriculture intensification involves intensive use of farm inputs, including water, fertilizers and pesticides. Such trends in agricultural intensification are not compatible with sustainable agriculture and are a threat to future production.
3) Protection and improvement of rural livelihoods, equity and social well-being. Agriculture can only become sustainable if it provides decent employment conditions to those who practice it, in an economically and physical safe, and healthy environment.
4) Enhanced resilience of people, communities and ecosystems. Increased climate variability impacts farmers and their production. Increased food price volatility affects both producers and consumers. Resilience, therefore, becomes central to the transition towards a sustainable agriculture and must address both the natural and the human dimensions.
5) Responsible and effective governance mechanisms. Agriculture is and will remain an economic activity driven by the need for those practicing it to make profit and ensure a decent living out of its activities. Sustainability will only be possible through effective and fair governance, including the right and enabling policy, legal and institutional environments with the right balance between private and public sector initiatives, and ensure accountability, equity, transparency and the rule of law.

These five principles of sustainable food production and agriculture are fully applicable to agricultural research and development including Integrated Pest Management (IPM). IPM in general and in the case of soil-borne pathogens in particular contributes to efficient use of natural resources building upon reduction of synthetic pesticides and utilization of genetic resistance coupled with creation of healthy under-ground and above ground environment. IPM especially when combined with conservation agriculture contributes to the development of long-term resilient production systems. One example is Hard Red Spring Wheat production system in Canada. Over the last 10-20 years, conservation agriculture has been dominating while wheat area reduced giving more land to food legumes and oil crops which contributed to healthy soils and reduction of wheat diseases. Farming communities became more resilient depending less of one crop and benefitting from a range of production options while reducing application of pesticides. It can be concluded that IPM is an important and essential component of sustainable agriculture, food production and food security and that more progress needs to be made to refine and improve on our management systems toward soil-borne pathogens and nematodes.

الملخص

ضبابات، عبد الفتاح، جول أوراكجي، فاتح طعمة، هانز براون، أليكس مورغونوف وريتشارد سيكورا. 2018. المكافحة المتكاملة لآفات التربة في القمح والإنتاج الزراعي المستدام. مجلة وقاية النبات العربية، 36(1): 37-44.

تهاجم الآفات المحمولة في التربة مثل أنواع النيماتودا الحوصلية من جنس *Heterodera* ونيماتودا تقرح الجذور (*Pratylenchus* spp.)، وتعفن التاج الذي تسببه فطور تابعة للجنس *Fusarium* جذور المحاصيل النجيلية وتؤدي إلى خسارة كبيرة في المحصول وانخفاض في نوعية وكمية الحبوب. وتكون هذه الخسارة أكثر حدة في المناطق التي تعاني نقصاً في المياه أو تسود فيها زراعة المحصول الوحيد سنة بعد أخرى. إن الإنتاج الزراعي المستدام للمحاصيل التي تعتمد فقط على مياه المطر والمعرضة للجفاف، وبخاصة في المناطق الجافة أو شبه الجافة، معرض أكثر من غيره لتأثيرات التغير المناخي بسبب الأتربة الجافة والأكثر حرارة. لذا كان من المهم التأكيد على قدرة النبات في الحصول على الكمية الكافية من الماء مهدد أكثر عند وجود النيماتودا المتطفلة على النبات والفطور المسببة لتعفن الجذور والموجودة في المحيط الجذري. إن استخدام طرق الإدارة المتكاملة للصحة النباتية، التي تعتمد على استعمال الأصناف الجديدة التي تحمل صفة المقاومة أو التحمل لهذه الكائنات الحية الممرضة بالإضافة إلى التقنيات التي تحفز نمو وصحة الجذور معززة بالاستراتيجيات الحديثة لإدارة النيماتودا كالاستخدام الرشيد لمبيدات النيماتودا مع الطرائق البيولوجية والممارسات الزراعية الصحيحة، إذ نحن بحاجة إلى كل ذلك لتحقيق إنتاج زراعي مستدام في البيئات الزراعية التي أصبحت الآن أكثر جفافاً في العديد من المناطق حول العالم. إن صفة المقاومة في النباتات، إن وجدت، هي طريقة صديقة للبيئة وفعالة بيولوجياً. إلا أن الاعتماد على صفة المقاومة كان ممكناً حتى الآن فقط إزاء أحد أنواع نيماتودا حوصلات الحبوب *Heterodera filipjevi* الموجودة في تركيا. إلا أن هذه الصفة لم تنقل بعد إلى أصناف القمح المزروعة على نطاق واسع في المنطقة. لذلك لا بد في الوقت الحاضر من الاعتماد على طرائق أخرى بديلة لتقليل الخسائر التي تسببها الممرضات المحمولة في التربة. أدت الغربلة الواسعة لعدد كبير من مدخلات القمح إزاء الممرضات المحمولة في التربة إلى تحديد مدخلات وراثية متوسطة المقاومة في نوعي القمح الشتوي والربيعي. إلا أن نيماتودا حوصلات الحبوب لا تزال تعتبر عائقاً أساسياً في العديد من مناطق زراعة القمح حول العالم. يتم سنوياً غربلة مئات من مدخلات القمح الوراثية وخطوط التربية لمعرفة مدى مقاومتها للممرضات في التربة في تجارب تجريها سيميت في تركيا، بالتعاون مع مؤسسة تنمية بحوث الحبوب الأسترالية والتي نتج عنها تحديد العديد من المصادر الوراثية بين مقاوم أو متوسط المقاومة. يعتبر بعض هذه الموارد الوراثية المقاومة جديد ولم تسجل سابقاً، وتم تحديد مواقع مورثات كمّية لها (QTLs). يمكن استخدام هذه الموارد الوراثية المقاومة الجديدة للممرضات المنقولة مع التربة في برامج التربية لانتخاب آباء واستخدام المقاومة في أصول وراثية نخبة متكيفة في المناطق التي تعاني من مشكلة هذه الممرضات. من أجل ذلك لا بد من تعاون وثيق بين أخصائي النيماتودا ومربي النبات وإخصائي المحاصيل لإيجاد حل لهذه المسائل المعقدة التي تواجه الإنتاج الزراعي، وذلك باستخدام نهج متعددة التخصصات للمضي قدماً في ضمان الأمن الغذائي للجميع. وقد ركزت البحوث الحديثة في برنامج الآفات المنقولة مع التربة في المركز الدولي لتحسين الذرة والقمح (سيميت) على غربلة الأصول الوراثية، وإمكانية استخدامها كمصادر للمقاومة، وكيفية إدخال المصادر الجديدة للمقاومة في برامج تربية النبات، على أن التربية لصفة المقاومة تعد عملية صعبة ومعقدة عند وجود أنواع وأنماط مرضية مختلفة في الطبيعة. هناك برامج بحثية حالية ومستقبلية لاستخدام العديد من الكائنات الدقيقة التي تعيش داخل أنسجة النبات وممارسات زراعية أخرى لتقليل الخسائر التي تحدثها الآفات المنقولة مع التربة. إن جهود التربية الحالية إزاء الآفات المنقولة مع التربة غير كافية نظراً للافتقار إلى الخبرة والاعتراف بالآفات المنقولة مع التربة كعامل محدد لإمكانية إنتاج القمح، واستراتيجيات التربية غير المناسبة، وبطء عمليات الغربلة وضعف تمويل البحوث وهي ركائز وأساسيات مطلوبة لنهج أكثر واقعية لإدارة صحة النبات.

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References

1. **Agrios, G.N.** 2005. Plant Pathology, 5th edition. Academic Press, New York, USA.
2. **Akinsanmi, O.A., V. Mitter, S. Simpfendorfer, D. Backhouse and S. Chakraborty.** 2004. Identity and pathogenicity of *Fusarium* Species Isolated from Wheat fields in Queensland and Northern New South Wales. Australian Journal of Agricultural Research, 55: 97-107.
3. **Aktaş, H., H. Bostancıoğlu, B. Tunalı and E. Bayram.** 1996. Determination of root and foot rot pathogens which are problems in Konya province and research and solution. Pages 392-403. In: Cereal Symposium book. Konya, Turkey.
4. **Allen, M.W., W.H. Hart and K.V. Baghott.** 1970. Crop rotation controls the barley root-knot nematode at Tulelake. California Agriculture, 24: 4-5.
5. **Angelo P.P. and V. Giovanni.** 2011. Fungal plant disease in Europe and in the Mediterranean basin. Agricultural Science: Enciclopedia of Life Support Systems (EOLLS), Publisher: Eolss Publisher.
6. **Apple J.L. and R.F. Smith.** 1976. Progress, Problems, and Prospects for Integrated Pest Management. Pages 179-196. In: Integrated Pest Management. J.L. Apple and R.F. Smith (eds). Springer, Boston, MA.
7. **Ashrafi, S., S. Helaly, H.J. Schroers, M. Stadler, K.R. Richert-Poeggeler, A.A. Dababat and O. Maier.** 2017. *Ijuhya vitelline* sp. nov., a novel source for chaetoglobosin A, is a destructive parasite of the cereal cyst nematode *Heterodera filipjevi*. PLoS ONE, 12 (7): e0180032. https://doi.org/10.1371/journal.pone.0180032

8. **Ashrafi, S., M. Stadler, A.A. Dababat, K.R. Richert-Pöggeler, M.R. Finckh and M. Wolfgang.** 2017. *Monocillium gamsii* sp. nov. and *Monocillium bulbillosum*: two nematode-associated fungi parasitising the eggs of *Heterodera filipjevi*. *MycoKeys*, 27: 21-38.
9. **Ashrafi, S., A.A. Dababat and W. Maier.** 2015. Towards harbouring the diversity of microorganisms associated with eggs and cysts of cereal cyst nematodes for biological control. Pages 285-288. In: Nematodes of Small Grain Cereals: current status and research. A.A. Dababat, H. Muminjanov and R.W. Smiley (eds). FAO, Ankara, Turkey.
10. **Ban, T.** 2000. Review studies on the genetics of resistance to Fusarium head blight caused by *Fusarium graminearum* in wheat. Pages 82-93. In: Proceedings of the International Symposium on Wheat Improvement for Scab Resistance. J. Raupp, Z. Ma, O. Chen and D. Liu (eds.). Suzhou and Najing, The Republic of China, May 5-11, 2000.
11. **Beed, F., A. Benedetti, G. Cardinali, S. Chakraborty, T. Dubois, K. Garrett and M. Halewood.** 2011. Climate change and micro-organism genetic resources for food and agriculture: state of knowledge, risks and opportunities. http://www.fao.org/docrep/meeting/022/mb392e.pdf
12. **Bruehl, G.W.** 1987. Soil borne plant pathogens, Macmillan Publishing Company, New York.
13. **Burgess, L.W., D. Backhouse, A.B. Pattison, B.A. Summerell, T.A. Klein, R.J. Esdaile and G. Ticehurst.** 1993. Long-term effects of stubble management on the incidence of infection of wheat by *Fusarium graminearum* Schw. Group 1. Australian Journal of Experimental Agriculture, 33: 451-456.
14. **Burgess, L.W., D. Backhouse, B.A. Summerell and L.J. Swan.** 2001. Crown rot of wheat. Pages 271-295. In: *Fusarium* – Paul E. Nelson Memorial Symposium. B.A. Summerell, J.F. Leslie, D. Backhouse, W.L. Bryden, and L.W. Burgess (eds). American Phytopathological Society, St. Paul, Minesotta.
15. **Burgess, L.W., R.L. Dodman, W. Pont and P. Mayers.** 1981. *Fusarium* diseases of wheat maize and grain sorghum in eastern Australia. Pages 64-67. In: Fusarium diseases, biology and taxonomy. P.E. Nelson, T.A. Toussoun and R.J. Cook (eds.). Pennsylvania State University Press, University Park.
16. **Chitwood, D.J.** 2003. Research on plant parasitic nematodes biology conducted by the United States Department of Agriculture – Agricultural Research Service. Pest management Science, 59: 748-753.
17. **Cook, R.J.** 1981. Fusarium diseases of wheat and other small grain in North America. Pages 39-52. In: Fusarium: Diseases, Biology and Taxonomy. P.E. Nelson, T.A. Toussoun and R.J. Cook (eds). Pennsylvania State University, University Park.
18. **Cook, R.J. and R.J. Veseth.** 1991. Wheat Health Management. American Phytopathol Society, St. Paul, MN.
19. **Cook, R.J.** 1992. Wheat root health management and environmental concern. Canadian Journal of Plant Pathology, 14: 76-85.
20. **Cook, R.J.** 2001. Management of wheat and barley root diseases in modern farming. Australasian Plant Pathology, 30: 119-126.
21. **Dababat, A.A., M. Imren, G. Erginbas-Orakci, S. Ashrafi, E. Yavuzaslanoglu, H. Toktay, S.R. Pariyar, H.I. Elekçioğlu, A. Morgounov and T. Mekete.** 2015. The importance and management strategies of cereal cyst nematodes, *Heterodera* spp., in Turkey. Euphytica, 202: 173-188.
22. **Dababat, A.A., S.R. Pariyar, J.M. Nicol, G. Erginbas-orakci, C. Wartin, M. Klix, N. Bolat, H.J. Braun and R.A. Sikora.** 2014. Influence of fungicide seed treatment on the integrated control of *Heterodera filipjevi* on six wheat germplasm with different levels of genetic resistance under controlled conditions. Nematropica, 44: 25-30.
23. **Diehl, J.A., R.D. Tinline and R.A. Kochhann.** 1983. Perdas em trigo causadas pela podridao comum de raizes no Rio Grande do Sul, 1979–1981. Fitopatologia Braseleira, 8: 507–511.
24. **Dodman, R.L. and G.B. Wildermuth.** 1987. Inoculation methods for assessing resistance in wheat to crown rot caused by *Fusarium graminearum* Group 1. Australian Journal of Agricultural Research, 38: 473-486.
25. **Fiers, M., V. Edel-Hermann, C. Chatot, B. Hingrat and C. Alabouvette.** 2012. Potato soil-borne diseases. A review. Agronomy for Sustainable Development, Springer Verlag/EDP Sciences/ INRA, 32: 93-132.
26. **Fouly, H.M., W.L. Pedersen, H.T. Wilkinson, and M.M. Abd El-Kader.** 1996. Wheat root rotting fungi in the old and new agricultural lands of Egypt. Plant Disease, 80: 1298-1300.
27. **Gurner, P.S., A.J. Dube and J.M. Fisher.** 1980. Chemical control of cereal cyst-nematodes (*Heterodera avenae*) on wheat by a new low-volume applicator. Nematologica, 26: 448-454.
28. **Hekimhan, H., A. Bağci, J.M. Nicol, Z. Arisoy, S. Taner and S. Sahin.** 2004. Dryland root rot: A major threat to winter cereal production under sub-optimal growing conditions. Page 283. In: Proceedings of the 4th International Crop Science Congress, 26 September - 1 October 2004, Brisbane, Australia.
29. **Karssen, G., W. Wesemael and M Moens.** 2013. Root-knot nematodes. Pages 74-108. In: Plant Nematology. P. Perry and M. Moens (eds.). 2nd Edition. CAB International, Wallingford, UK.
30. **Klein, T.A., L.W. Burgess and F.W. Ellison.** 1991. The incidence and special patterns of wheat plants infected by *Fusarium pseudograminearum* Group 1 and the effect of crown rot on yield. Australian Journal of Agricultural Research, 42: 399-407.
31. **Lucas, P.** 2006. Diseases caused by soil borne pathogens. Pages 373-386. In: The Epidemiology of Plant Diseases. B.M. Cooke, D. Gareth Jones and B. Kaye (eds). The Netherlands, Springer.
32. **Lukyanenko, A.N.** 1991. Disease Resistance in Tomato. Pages 99-119. In: Genetic Improvement of Tomato. Monographs on Theoretical and Applied

Genetics, vol 14. G. Kalloo (ed). Springer, Berlin, Heidelberg.

33. **Mc Donald, A.H. and J.M. Nicol.** 2005. Nematode parasites of cereals. Pages 131-191. In: Plant-parasitic nematodes in subtropical and tropical agriculture. M. Luc, R.A. Sikora and J. Bridge (eds). Wallingford, UK, CAB International.
34. **Mendes, R., P. Garbeva and J.M. Raaijmakers.** 2013. The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. FEMS Microbiology Reviews, 37: 634-663.
35. **Nicol, J., R. Rivoal, S. Taylor and M. Zaharieva.** 2004. Global Importance of Cyst (*Heterodera* spp.) and Lesion Nematodes (*Pratylenchus* spp.) on Cereals: yield loss, population dynamics, use of host resistance and integration of molecular tools. Nematology Monographs and Perspectives, 2: 233-251.
36. **Nicol, J.M., N. Bolat, A.F. Yildirim, A. Yorgancilar, A. Kaplan and H.J. Braun.** 2005. The Cereal Cyst Nematode is causing economic damage on rainfed wheat production systems of Turkey. Joint Meeting of the Annual Western Soil Fungus Conference and the American Phytopathology Society Pacific Division, Portland, United States of America, 28 June- 1st July.
37. **Oerke, E.C.** 2006. Crop losses to pests. Journal of Agricultural Science, 144: 31-43.
38. **Oerke, E.C., H.W. Dehne, F. Schönbeck and A. Weber.** 1994. Crop production and crop protection. Estimated losses in major food and cash crops. Amsterdam: Elsevier.
39. **Pariyar, S.R., A.A. Dababat, W. Sannemann, G. Erginbas-Orakci, A. Elashry, S. Siddique, A. Morgounov, J. Leon and F.M.W. Grundler.** 2016. Identification of wheat resistance to cereal cyst nematode *Heterodera filipjevi* through association mapping. Phytopathology, 106: 1128-1138.
40. **Parry, D.W.** 1990. The incidence of *Fusarium* spp. in stem bases of selected crops of winter wheat in the Midland, UK. Plant Pathology, 39: 619-622.
41. **Parry, D.W., P. Jenkinson and L. Mcleod.** 1995. *Fusarium* ear blight (scab) in small grain cereals-a review. Plant Pathology, 44: 207-238.
42. **Paulitz, T.C., R.W. Smiley and R.J. Cook.** 2002. Insights into the prevalence and management of soilborne cereal pathogens under direct seeding in the Pacific Northwest, USA. Canadian Journal of Plant Pathology, 24: 416-428.
43. **Rivoal, R. and R. Cook.** 1993. Nematode pests of cereals. Pages 259-303. In: Plant-parasitic Nematodes in Temperate Agriculture. K. Evans, D.L. Trudgill and J.M. Webster (eds). CAB International, Wallingford, UK.
44. **Rivora, A. and R.J. Cook.** 2008. Impact of soil- borne pathogens of cereals on grain production. Advanced Theoretical Training Manual.
45. **Sikora, R.A.** 1992. Management of the antagonistic potential in agricultural ecosystem for the biological control of plant parasitic nematodes. Annual Review of Phytopathology, 30: 245-270.
46. **Sikora, R.A., J. Bridge and J.L. Starr.** 2005. An overview of integrated nematode management technologies. Pages 793-825. In: Plant parasitic nematodes in subtropical and tropical agriculture (2nd ed.). M. Luc, R.A. Sikora and J. Bridge (eds). CAB International, Wallingford, UK.
47. **Singh, R.P., E.J. Huerta, G. Fuentes, E. Duveiller, L. Gilchrist, M. Henry and J.M. Nicol.** 2005. Resistance to Diseases, Chapter 10. Pages 291-327. In: Durum Wheat Breeding: Current Approaches and Future Strategies. C. Royo, M. Nachit, N. Di Fonzo, J. Araus, W.P. Pfeiffer and G. Slafer (eds). Food Product Press, Haworth Press Inc, New York, USA.
48. **Singh, D. and K. Agrawal.** 1987. Ear cockle disease (*Anguina tritici* (Steinbuch) Filipjev) of wheat in Rajasthan, India. Seed Science and Technology, 15: 777-784.
49. **Smiley, R.W. and L.M. Patterson.** 1996. Pathogenic fungi associated with *Fusarium* foot rot of winter wheat in the semiarid Pacific Northwest, Plant Disease, 80: 944-949.
50. **Smiley, R.W., J.A. Gourlie, S.A. Easley and L.M. Patterson.** 2005. Pathogenicity of fungi associated with the wheat crown rot complex in Oregon and Washington. Plant Disease, 89: 949-957.
51. **Smith, R.F., J.L. Apple and D.G. Bottrell.** 1976. The origins of integrated pest management concepts for agricultural crops. Pages 1-16. In: Integrated Pest Management. J.L. Apple and R.F. Smith (eds.). Springer, Boston, MA.
52. **Specht, L.D. and C.M. Rush.** 1998. Fungi associated with root and foot rot of winter wheat and populations of *Bipolaris sorokiniana* in the Texas panhandle. Plant Disease, 72: 959- 969.
53. **Teng, P.S.** 1987. Crop loss assessment and pest management. St Paul: APS Press.
54. **Teng, P.S. and S.V. Krupa.** 1980. Assessment of losses which constrain production and crop improvement in agriculture and forestry. Proceedings of the E.C. Stackman Commemorative Symposium. St. Paul: University of Minnesota.
55. **Tulek, A., I. Kepenekci, T.H. Cifticigil, I. Ozturk, K. Akin, M. Seidi, M. Yildirim and A.A. Dababat.** 2015. Effects of seed-gall nematode, *Anguina tritici*, on bread wheat grain characteristics and yields in Turkey, Nematology, 17: 1099-1104.
56. **Tunali, B., J.M. Nicol, F.Y. Erol and G. Altıparmak.** 2006. Pathogenicity of Turkish crown and head scab isolates on stem bases on winter wheat under greenhouse conditions. Journal of Plant Pathology, 5: 143-149.
57. **Vanstone, V.A., A.J. Rathjen, A.H. Ware and R.D. Wheller.** 1998. Relationship between root lesion nematodes (*Pratylenchus neglectus* and *P. thornei*) and performance of wheat varieties. Australian Journal of Experimental Agriculture, 38: 181-188.
58. **Wagacha, J.M. and J.W. Muthomi.** 2006. *Fusarium culmorum*: Infection process, mechanism of mycotoxin production and their role in pathogenesis in wheat. Crop Protection, 26: 877-885.

59. **Whitehead, A.G.** 1998. Plant Nematode Control. CAB International, Wallingford, UK. 384 pp.

60. **Windels, C.E. and J.V. Wiersma.** 1992. Incidence of *Bipolaris* and *Fusarium* on subcrown internodes of spring barley and wheat grown in continuous conservation tillage. Phytopathology, 82: 699-705.

61. **Yahyaoui, A., J. Nicol, A. Bağcı, N. Bolat, M. Nachit, R. Rivoal, N. Nsarellah, H. Ketata, H. Braun, H. Hekimhan, M. Mergoum, B. Tunali, H. Ekiz, and M. Keser**. 2003. Importance and control of cereal root diseases in West Asia and North Africa. Page 639-640. In: 1st Central Asian Wheat Conference, Almaty, Kazakhstan, June 10-13, 2003.