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# Sustainable Improvements in Diagnostic Capabilities of Plant Health Practitioners through Short In-Service Training

Stefan Toepfer <sup>1,\*</sup>, Celestin Niyongere <sup>2</sup>, Privat Ndayihanzamaso <sup>2</sup> , Deo Ndikumana <sup>3</sup>, Willy Irakoze <sup>2</sup>, Eustache Cimpaye <sup>4</sup>, Dismas Minani <sup>5</sup>, Pascal Bindariye <sup>6</sup> and Willis Ochilo <sup>7</sup> 

<sup>1</sup> CABI Switzerland, 2800 Delemont, Switzerland

<sup>2</sup> Institute of Agricultural Science ISABU, Bujumbura P.O. Box 795, Burundi; niyocelstin@gmail.com (C.N.); ndayihanzamasoprivat@gmail.com (P.N.); w\_irakoze@yahoo.com (W.I.)

<sup>3</sup> Faculty of Agriculture FABI, University of Burundi, Bujumbura P.O. Box 2700, Burundi; drnddeo2015@gmail.com

<sup>4</sup> Department of Plant Protection DPV, Ministry of the Environment, Agriculture and Livestock MINEAGRIE, Gitega P.O. Box 161, Burundi; cimpeust@gmail.com

<sup>5</sup> Provincial Agriculture and Livestock Bureaux BPEAE, DGMVAE, Ministry of the Environment, Agriculture and Livestock MINEAGRIE, Gitega P.O. Box 161, Burundi; dismasminani@rocketmail.com

<sup>6</sup> Bureau d'Etudes et des Curricula de l'Enseignement Post Fondamental Technique et de la Formation Professionnelle BECEPTF, Ministry of Education, Bujumbura P.O. Box 5132, Burundi; pbindariye@gmail.com

<sup>7</sup> CABI Africa, Nairobi P.O. Box 633-00621, Kenya; w.ochilo@cabi.org

\* Correspondence: s.toepfer@cabi.org

**Abstract:** Many growers rely on good agricultural extension services to successfully grow their crops. Correct field diagnoses of plant health problems are an essential starting point. However, some agricultural extension workers may have had limited capacity building in field diagnosis during their agricultural education, and many may have had limited or no continuing education possibilities during their advisory work life. As a result, errors may occur in the course of diagnosis of plant health problems with devastating consequences. The objective of this study, therefore, was to assess the value of short and inexpensive in-service training that is intended to improve the quality of field diagnosis of plant health problems. Eight groups of agricultural extension workers totaling 165 participants were trained during a 3-day-long intensive course in the diagnosis of plant health problems as part of the plant doctor training in the Plantwise program in Burundi ( $44 \pm 9$  years of age,  $14 \pm 10$  years of experience in agriculture and  $8 \pm 7$  years in extension; 10% females). Empirical data from before-versus-end and after-course analyses revealed that such courses can indeed increase knowledge and skills in field diagnosis by  $20 \pm 8\%$  points during the training and by  $9 \pm 4\%$  points when having worked for 8 to 19 months after training. The level of variability among extension workers was also reduced by  $0.8 \pm 1\%$  points pre-course versus end-course, and by  $1.1 \pm 0.3\%$  points from pre- versus post-course. Interestingly, there seemed little to no influence of work experience in agricultural extension on the quality of field diagnosis of plant health problems. More advanced educational levels only slightly improved the diagnosis quality of extension workers; gender played no role; younger workers performed slightly better than older ones. This may indicate a lack of opportunities for further training as part of continuing adult education. Our results suggest regularly repeated in-service training for agricultural practitioners may be beneficial. Investments in such training seem worthwhile since better diagnoses can lead to more appropriate pest management advice and judicious use of pesticides.

**Keywords:** Plantwise; diagnosis of plant health problems; agricultural extension services; plant clinics; agricultural education; capacity building; continuing professional education



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## 1. Introduction

Many growers around the world rely on good agricultural extension services to grow their crops successfully [1]. Consumers demand safe and healthy food and desire, at the

same time, to conserve their environment [2,3]. Although the approaches to delivering agricultural services vary across countries [1,4], they usually start with a proper diagnosis of the problem, normally a plant health-related problem, that the grower tries to manage and seeks advice on.

About 10 to 40% of global crop losses are attributed to pests and diseases [5]. Coupled with this, the diagnosis of certain plant health problems by extension workers is problematic [6,7]. On the one hand, diagnoses may become challenging just because of the large diversity of different abiotic and biotic problems different crops may suffer from. Biotic problems may consist of a large diversity of possible pests, such as insects, mites, nematodes, mollusks, birds, mammals or others, as well as of diseases, such as viruses, phytoplasma, oomycetes, fungi or bacteria [8]. Moreover, those problems may occur on a relatively large variety of crops. On the other hand, knowledge of the crop history is often needed for a proper diagnosis, as well as on the temporal and spatial dynamics of the problem in the considered field. An extension worker has often no direct access to such information if not visiting the considered farm [9]. Therefore, the diagnosis of a plant health problem demands not only technical but also communication skills of the extension worker with the grower to obtain a holistic set of information [9]. Depending on the type of extension worker (governmental, private, connected to agri-input business or not), certain conflicts of interest may also play a role in pest diagnosis, although this problem is considered relatively minor [9,10]. All in all, it can become a real challenge to properly diagnose a certain plant health problem a grower has in their field. Therefore, subsequent management advice may not be optimal or may even be ineffective or not economical [7,11].

Therefore, the global Plantwise program invests in improving agricultural extension services within a plant health system approach [12,13]. The Plantwise program uses plant clinics as a demand-driven service for growers run by frontline agricultural extension workers to reach more growers than traditional office- or field-visit-based extension methods [9] or Farmer Field Schools [14]. Plant clinic sessions are typically held regularly at public places convenient to both growers and local agricultural extension workers, e.g., at markets, retailer points or central places of grower cooperatives, associations, or similar places [12]. An agricultural extension worker provides on-the-spot diagnosis and advice for a grower who brings a plant health query to the plant clinic [13]. The diagnosis and advice are provided to the grower in the form of a written prescription, either in paper form or electronically, as employed by the human health system. Prescription helps the grower to diagnose a plant health problem and to better manage their crop or to seek appropriate inputs at an agri-input shop.

One key component of Plantwise is the enforcement of the capacities of agricultural extension workers. This is largely achieved through in-service training of extension practitioners [15]. The training comprises a comparable quantity of different training modes such as field excises, classroom exercises, interactive presentations, case studies and handouts as reference materials for the extension work back at the workplace and for consolidative self-study (see Supplementary Materials). These multiple training modes allow for repetition and consolidation as well as for interaction, and enable learners to process and apply information as reported to be a successful approach in in-service training [16,17]. By 2022, Plantwise had entered 36 countries and trained more than 13,000 extension workers as plant doctors. The plant doctor training primarily includes capacity building in field diagnosis and plant clinic establishments, referred to as the plant doctor training module 1 of Plantwise [18]. However, the training program also includes capacity building in proper pest management advice (Plantwise module 2), optionally biological control, invasive species management, data capturing and handling, monitoring and assuring quality, mass extension campaigns, gender, and many other aspects. Although the positive effects of such training for pest management in agriculture have been somewhat documented [16] including the phase-out of hazardous pesticides [7], reports on effects on better pest diagnosis, or more generally on better job performance back in the workplace, are scarce and

largely anticipated [19]. This could potentially hinder decision-makers to invest in such training or the target audience to participate [16,19,20].

We therefore surveyed eight groups of agricultural extension workers who had been trained in a short 3-day-long intense course in plant health problem diagnosis as part of the plant doctor training in the Plantwise program. The study was conducted in Burundi, but is likely relevant to other countries with functional agricultural extension systems. The purpose of the study was to determine whether such short adult education and in-service training of practitioners in agricultural extension could indeed improve the quality of diagnoses, as often anticipated [19]. Moreover, we tested several factors that may underlay the effects of such training. For example, it was hypothesized that more experienced or older extension workers may provide higher-quality advice due to their field experience than less experienced or younger workers. Or, vice versa, they may provide less quality advice due to a larger time lag since their main education [7]. Further, it was hypothesized that the level of education, as well as gender, may influence the quality of field diagnosis [8]. We believed that many of those factors may contribute to a better diagnosis of plant health problems provided to the grower. Consequently, they may positively impact the appropriate choice of management options and consequently crop production. This would in turn improve food security and/or food safety. It is hoped that our findings will contribute to this aspect and can estimate the level of importance of reinforcement of the capacity of extension workers in the proper diagnosis of plant health problems. Decision-makers among the stakeholders of a plant health system may consider the findings.

## 2. Materials and Methods

### 2.1. Study Population

The global Plantwise program uses public, free-of-charge and easily accessible plant clinics as a demand-driven advisory service to growers. The agricultural extension worker, who serves as a ‘plant doctor’ in a plant clinic, has an agricultural education background but has additionally received capacity building through Plantwise training. The latter is being studied here for its effects on gains of knowledge and skills by participants. Once trained, the plant doctor provides on-the-spot diagnosis and advice for growers who bring their plant health queries to the plant clinics. The diagnosis and advice are provided to the grower in the form of a written prescription (paper or electronic) as employed by the human health system. The prescription is thought to help a grower to better diagnose plant health problems on the farm and to better manage their crop.

In this survey, 165 agricultural extension practitioners and experts in Burundi were studied (study population, Table 1). The majority of the studied extension workers (64%) originated from local agricultural extension units (commune = district level) and only some were from even more local or from higher administrative levels. Two to four representative districts and their extension workers were selected with regard to achieving good coverage across climatically distinct zones from each of the eight provinces of Burundi. Therefore, the study population is believed representative of around 3000 governmental agricultural extensionist workers of the country (target population). Most participants were government employed, from the public sector. Of the participants, 64% worked as plant doctors, 8% doubled up as both plant doctors and plant doctor trainers, and 28% were solely trainers of plant doctors. The male:female ratio was 90:10%, and the average age was  $44 \pm 10$  SD years (min 27, max 60 years). The range of educational levels of participants was rather large, which helped us to analyze the importance of this factor for training in agricultural extension, that is, 17% of the studied agricultural extension workers had education as agricultural technicians at the A3 level (i.e., a 10-year + 1 to 2 years of education), 73% as agricultural technicians at the A2 level (10 + 3 to 4 years), 2% had the A1 level (12 or 13 years + 3 years of university, like a Diploma or BSc). About 3% had a BSc in agriculture (12 or 13 years + 3 to 4 years of university), and 3% had a university degree as agricultural engineers (A0 level, 12 or 13 years + 5 years of university). Among the plant doctor trainers, few participants had an MSc (12 to 13 years + 3 to 4 + 2 years of university) or even a

PhD. Studied agricultural extension workers had around  $14 \pm 10$  years of experience in agriculture and  $8 \pm 7$  years in extension.

**Table 1.** Characteristics of 165 studied agricultural extension practitioners and experts (study population) that received a short re-enforcement in-service training in the diagnosis of plant health problems, and the percentage of correct diagnosis achieved. Eight training groups assessed (replicates) in Burundi in 2021 and 2022. Average values and standard deviations (SD) presented.

Characteristics of Training Participants	Mean	SD	Max	Min
Participants per course (total 165)	21	4	25	15
Age (years)	44	9	60	27
Gender (% male:female)	90:10	12	100:0	67:33
Years in agriculture (#)	14	10	36	0
Years in extension (#)	8	7	23	0
Years since finishing education (#)	7	5	13	1
Correct diagnosis of plant health problem, pre-course (%)	43	5.6	80	5
Correct diagnosis of plant health problem, end-course (%)	63	7.7	97	27
Correct diagnosis of plant health problem, several months after the course (%)	52	3.6	76	31

## 2.2. Treatments

In this study, agricultural extension practitioners and experts, as described above and in Table 1, were trained in broad principles of field diagnosis of plant health problems during a practical, adult education, in-service training (Figure 1). This training ran as a three-day block course (24 h or 32 lessons) (see Supplementary Materials). The training was aimed at building capacity in properly diagnosing plant health problems growers may bring to a plant clinic. The training builds on and reinforces the existing skills and capacities of extension workers. The training is tailored to a broad audience of practitioners in agricultural extension that have at least, but not exclusively, basic agriculture education. Due to its practical nature and combination of training modes [17], the same course has been and can be provided to a diverse audience including experts with higher education levels. The training has been validated in more than 30 countries and subsequently updated and adapted. The training is therefore supposed to universally fit to the needs of a diverse group of agricultural extension practitioners and experts. The training comprises a comparable quantity of field exercises, classroom exercises, interactive presentations, case studies, and handouts as references aiding the extension work back at the workplace as well as for self-study. Eight of such trainings with 15 to 25 trainees each were assessed in Burundi, i.e., two in March, one in August, three in November 2021, and one in March and one in May 2022 (Table 1).

## 2.3. Data Assessment

To examine the effects of training on the quality of field diagnosis, a pre-course assessment was conducted and then compared to an end-course assessment as well as to an assessment 8 to 9 months after training. In each assessment, at least 20 multiple-choice questions were asked on different cases of field diagnosis, with at least one answer being correct. Most questions were connected to a photo showing symptoms or signs of a plant health problem. The percentage of correct answers before the course was subtracted from the correct answers at the end of or months after the course to measure the change in diagnosis quality by the extension workers due to the training (in percent points). Similarly, the variability of exam scores, thus of knowledge and skills, was compared as percent point change in standard error of the mean (SEM). In addition, characteristics of the participants such as educational background, years since finishing agricultural education, years working

in agriculture and/or extension, age, and gender were collected using personal profile questionnaires. Those data were linked to the course assessments in an anonymized way.



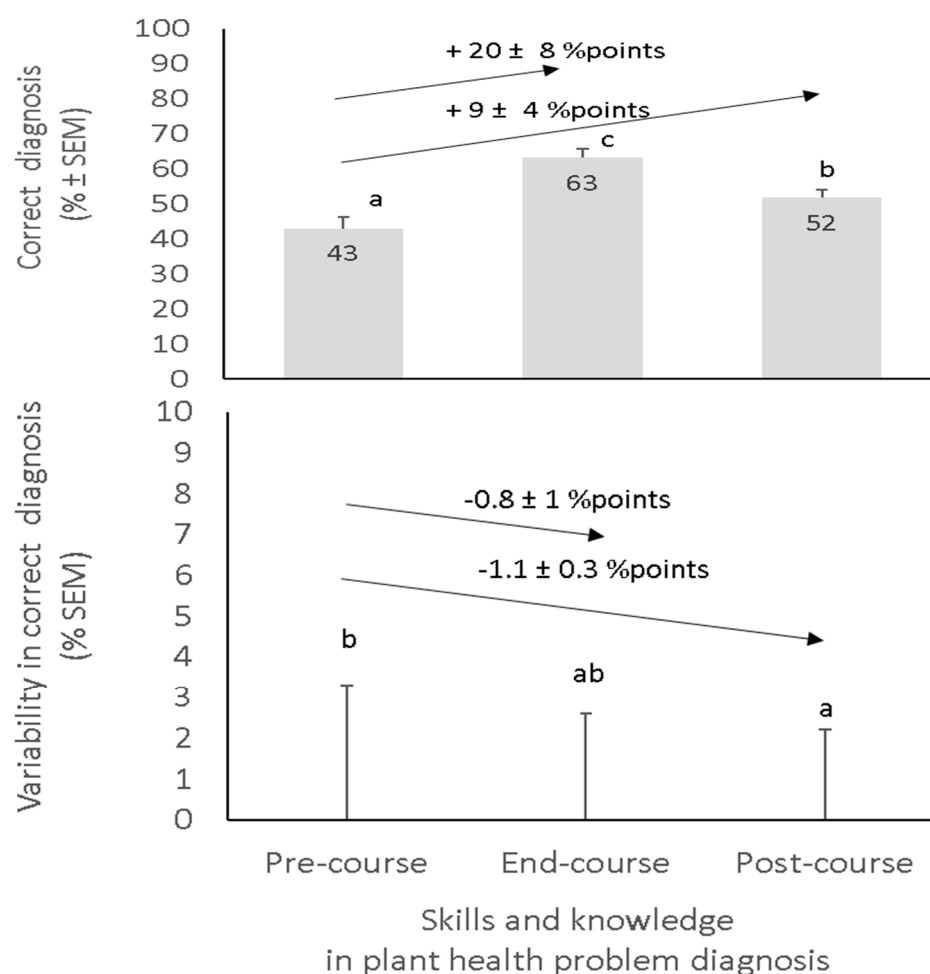
**Figure 1.** Education logic of each topic trained (A), and of the entire training objectives (B) during short 3-day re-enforcement in-service training of agricultural extension workers in the field diagnosis of plant health problems as part of the Plantwise programme. The training is provided in local language.

#### 2.4. Data Analysis

The following factors were analyzed for their potential influence on the quality of the diagnosis: the actual training, the time after training, educational background, years since finishing agricultural education, experiences as years working in agriculture and/or extension, age, and gender. Before any factorial analyses, the normality of data was assessed through histograms and Q.Q plots. The equality of variances was assessed using Levene's Test. Independent sample *t*-tests were applied for pairwise comparisons, regression analyses were employed for establishing relationships between variables, and General Linear Models (GLM) were used for factorial analyses with a Tukey HSD or Games Howell post hoc for multiple comparisons depending on equality of variances [21]. IBM SPSS 13.0 statistical software was used.

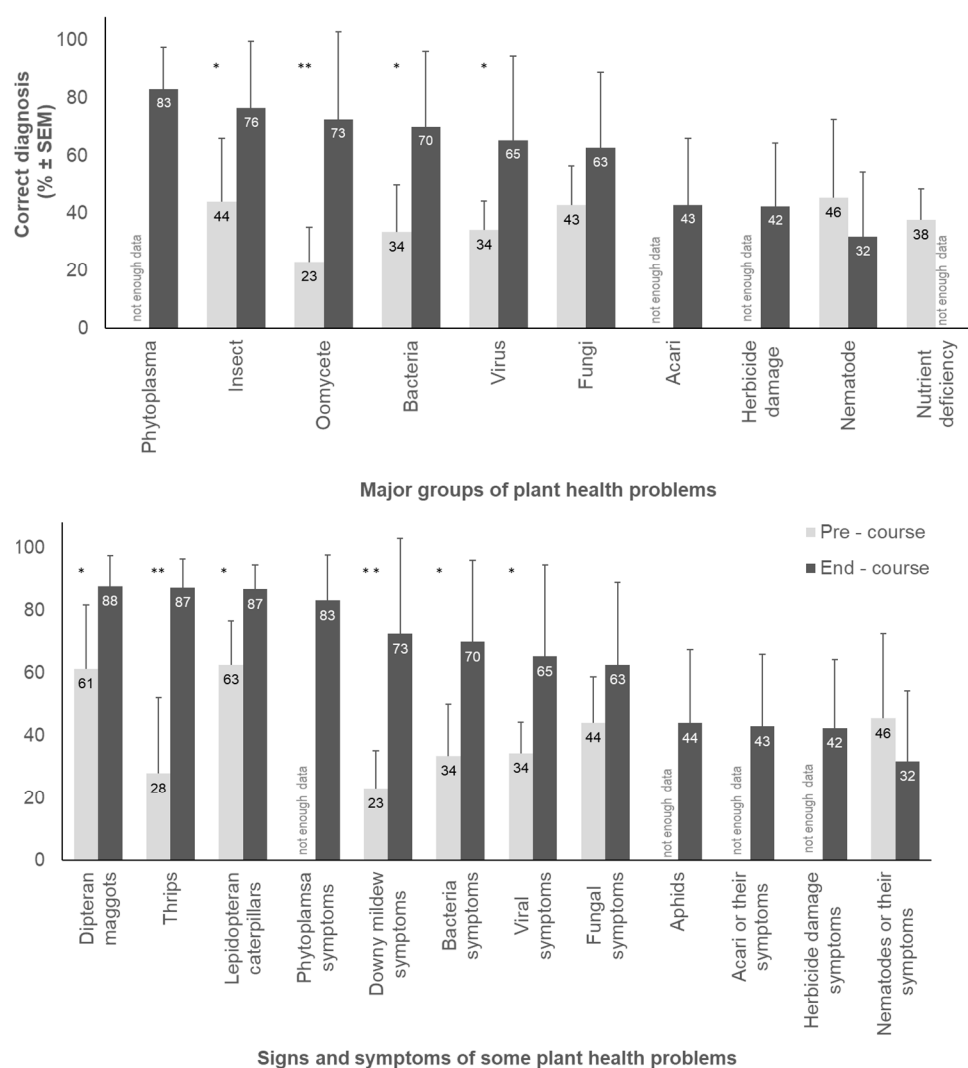
### 3. Results

A 3-day intense, in-service, block course in field diagnosis of plant health problems can improve the proportion of correct diagnosis (before–after paired *t*-test, *df* = 7, *t* = −6, *p* = 0.0047, Figure 2). In fact, agricultural extension workers improved their knowledge and skills in field diagnosis by around  $20 \pm 8\%$  points during the training. However, when having worked for 8 to 19 months after training, this training effect appeared slightly less frequently, i.e.,  $8.7 \pm 3.6\%$  points. The variability in correct field diagnosis among the diverse extension workers was slightly reduced, namely by  $-0.8 \pm 1\%$  points pre-versus end-training, and by  $-1.1 \pm 0.3\%$  points pre-versus post-training (*t*-tests, *p* = 0.19, *p* = 0.01).



**Figure 2.** Changes in knowledge and skills concerning quality of the diagnosis of plant health problems by agricultural extension workers before and after a short in-service training in field diagnosis (Plantwise module 1) as well as 8 to 19 months after training in Burundi in 2021 and 2022. Average and variability as standard error of mean (SEM) as well as percent point changes shown. Eight trainings assessed (replicates), with  $21 \pm 4$  participants each, totaling 165 participants. Different letters on bars indicate significant differences as per *t*-test at *p* < 0.05.

Agricultural extension workers improved their skills of diagnosis for most groups of plant health problems, particularly for diagnosing insects, oomycetes, bacteria and viruses (Figure 3). Some signs or symptoms remained challenging to be correctly diagnosed despite training, such as mites and their damage, damage symptoms by herbicides, and symptoms of nematodes (Figure 3).



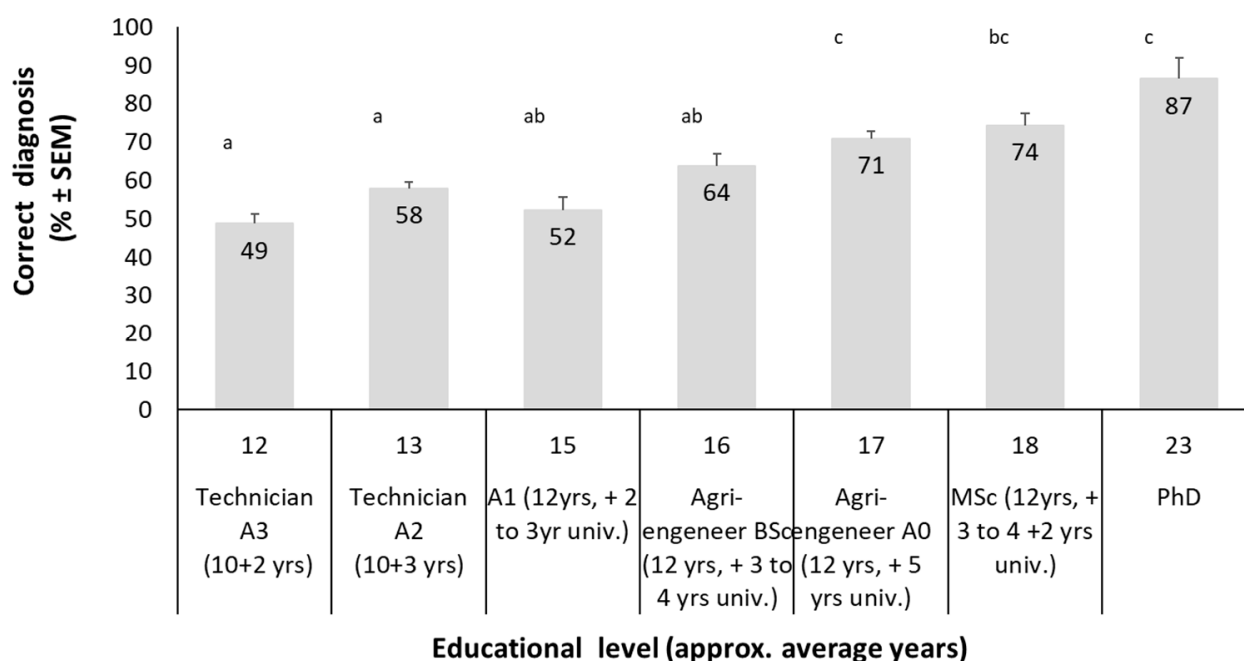
**Figure 3.** Improvement in knowledge and skills concerning quality of the diagnosis of certain plant health problems by agricultural extension workers before and after a short in-service training in field diagnosis (Plantwise module 1). Eight trainings assessed (replicates), with  $21 \pm 4$  participants each, totaling 165 participants. Stars on bars indicate significant differences as per paired sample *t*-test at \*  $p < 0.05$  and \*\*  $p < 0.005$  after *fdr* correction.

As hypothesized, educational levels influenced the knowledge and skills of an extension worker in correctly diagnosing plant health problems, although only slightly (Table 2, Figure 4). Extension workers with higher education levels such as a 5 year-university diploma, MSc or PhD achieved comparatively high diagnosis quality. These were followed by comparable levels of technical colleges (3-year vocational pieces of training at the secondary level) as well as different types of 3–4 years of university levels. Plantwise trainers performed slightly better than plant doctors due to their higher educational levels, but not due to their role as plant doctors or trainers (plant doctor:  $60 \pm 14$ , trainer:  $71 \pm 15$ , trainer + plant doctor:  $67 \pm 12\%$  correct diagnosis). Gender had no importance in diagnosis quality (males:  $61 \pm 16\%$ , females:  $63 \pm 13\%$  correct diagnosis, Table 2).

**Table 2.** Factors potentially influencing the quality of field diagnosis of plant health problems by agricultural extension workers. Eight groups assessed (replicates), with  $21 \pm 4$  participants each, totaling 165 participants. Burundi in 2021 and 2022. \* significant at  $p < 0.05$ , \*\* at  $<0.005$ , n.s.—not significant.

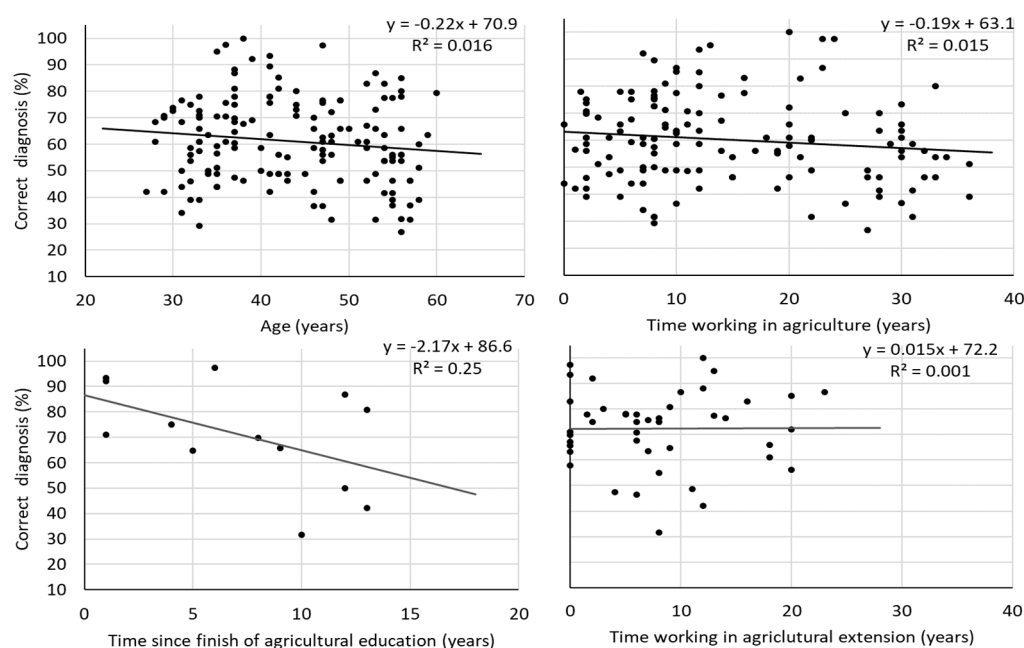
Influences on Quality of Diagnoses of Plant Health Problems					
Factor	df	t or F	p		
Training	6	−6.8	0.0047	**	Paired sample <i>t</i> -test
Gender	1; 147	−0.9	0.38	n.s.	Independent sample <i>t</i> -test
Education	7; 164	3.4	<0.002	**	Multi-variate GLM
Function in Plantwise <sup>1</sup>	2; 164	0.2	0.82	n.s.	
Age	6; 11	−2.6	0.047	*	Multiple Linear regression
Years working in agriculture	6; 11	0.2	0.82	n.s.	
Years working in agri-extension	6; 11	−0.001	1.00	n.s.	
Years working in agri-research	6; 11	2.2	0.08	n.s.	
Years since finishing education	6; 11	0.7	0.54	n.s.	

<sup>1</sup> Plant doctor only or plant doctor + trainer or trainer only.



**Figure 4.** Difference between educational levels concerning quality of field diagnosis of plant health problems by agricultural extension workers. Eight groups assessed (replicates), with  $21 \pm 4$  participants each, totaling 165 participants. Burundi in 2021 and 2022. Different letters on bars indicate significant differences as per Tukey HSD post hoc multiple comparisons test at  $p < 0.05$ .

Unexpectedly, years and types of experience did not improve diagnosis quality, such as years working in agriculture, extension, or research (Figure 5). In contrast, increasing age slightly reduced diagnosis quality.



**Figure 5.** Relationship between temporal factors and the quality of field diagnosis of plant health problems by agricultural extension workers. Eight trainings assessed (replicates), with  $21 \pm 4$  participants each, totaling 165 participants. Burundi in 2021 and 2022. Simple linear regression analyses applied (model statistics in Table 2).

#### 4. Discussion

The presented study shows that short in-service re-enforcement courses for agricultural extension workers can improve the quality of their diagnosis of plant health problems sustainably by nearly 10%. This is encouraging as short courses, such as the 3-day course studied here, might be in the financial possibilities of plant health system stakeholders or even of the agricultural extension workers themselves. In countries where networks of agricultural extension services do not exist [22], even growers may be targeted with a similar approach.

Improvements in the diagnosis of plant health problems are believed to lead to more appropriate pest management advice [23], and, in turn, may reduce wrong-targeted and therefore unnecessary use of pesticides. Although detailed multiple-region studies are largely lacking, it is indeed believed that a large proportion of pesticides are sprayed against the wrong target, and are therefore ineffective and/or unnecessary [24]. For example, many fungicides effective against ascomycete fungal plant diseases might be sprayed against oomycete diseases (Taylor and Reeder, CABI, 2020, pers. comm). Many fungicides may be also sprayed against bacterial diseases despite, except for copper-based products, being ineffective. Often, abiotic causes of plant health problems are treated with pesticides.

Due to the large diversity of plant health problems that extension workers face on different crops that growers may bring or report about, a proper diagnosis becomes challenging. Therefore, the global Plantwise program is investing in improving the knowledge, skills and capacities of agricultural extension workers (trained as plant doctors) to improve services to growers [14]. Short courses are applied to build on existing knowledge and skills, and consolidating and updating such. The here-studied training comprises a comparable quantity of different training modes such as field excises, classroom exercises, interactive presentations, case-based learning and handouts as reference materials and for consolidative self-study [19]. These multiple training modes as suggested by education experts [17] have been used, validated, their optimal ratio developed and their contents updated by more than 30 Plantwise countries. We therefore believe that those courses are suitable for a wider audience in the area of plant protection and agricultural extension with different backgrounds and cultural as well as agricultural settings [17,19,25].

However, the here-reported gains in knowledge and skills through such training have been often assumed, but rarely analyzed [19]. This might be due to challenges in defining evaluation criteria during and particularly after training as well as difficulties in assessing and concluding impact [19]. Although our study did not focus on specific training approaches, our analysis showed, as mentioned above, that short, practical in-service courses can significantly increase knowledge and skills in field diagnosis of plant health problems by nearly 10% of points. Although this is only the cumulative effect of a training, and specific components could not be analyzed separately, the general usefulness of such a training seems clear. It has been, in the case of Burundi, a change from 43 to 52% of correct diagnosis of plant health problems of the advised growers. The overall proportion of about half of the correct diagnoses may still seem low. However, these values were generated from diagnoses based on photographs during the training assessments. At work, the diagnosis quality by an agricultural extension worker is usually more accurate. This is, because they may have a plant sample the grower brought. The field situation, history and severity of the plant health problem can be discussed with the grower. Those provide essential help for proper diagnosis. In China, for example, more than 95% of diagnoses made by trained plant doctors at a plant clinic are usually correct if the grower brings a sample, and in Sri Lanka, the percentage is around 60% [11]. Conclusively, we believe that the knowledge and skills gained during short diagnostics courses, such as those provided by Plantwise, have helped to increase levels of correct diagnoses in different countries, including the here-studied situation of Burundi. Interestingly, the effect of training was higher from pre- to end-training (about 20% improvement) than when comparing the pre-training situation to that observed many months later (about 10% improvement). This shows that, despite consolidation and case-based exercises during the training [16,17], only a proportion of the newly acquired skills and knowledge is consolidated. This, in turn, calls for more regular repetitive in-service refresher trainings to assure better learning outcomes [17]. However, the 10% improvement already suggests a sustainable improvement of performance of extension officers back in the workplace [19]. Whether the training also impacts behavioral changes is difficult to conclude from the here-gained data [19] and may require further study.

Our study also showed, as hypothesized, that educational levels may influence the skills of extension workers in correctly diagnosing plant health problems. However, this effect appeared less pronounced than expected. For example, agricultural extension workers with vocational training background (secondary education level) can be as skilled as workers with a 3 to 4-year university background (roughly BSc level), which is encouraging as it would allow quality services for growers on local levels in a country. This indicates that educational levels may not play a major, key role in skills in field diagnosis as long as the extension worker has at least basic agriculture education. This confirms observations from Kenya (Bonilla J, Brudevold-Newman A, Molotsky, pers. comm), but contradicts the findings from Sri Lanka [11]. Also, gender played no role in diagnosis quality, but the proportion of females in agricultural extensions in Burundi is small as it is the case in many countries [26].

Interestingly, there seems to be little to no influence of work experience in different agricultural fields on the quality of field diagnosis of plant health problems. This includes experiences such as general agriculture, agricultural extension, research or education (Table 2). In addition, young workers seem to perform even slightly better than older ones. It is difficult to judge why experiences play, if any, a minor role. It might be that the problems in field diagnosis are of general nature and cannot be easily improved through experience such as the discovery of new disease groups such as phytoplasma. It may also be a result of challenges in assessing information as often reported from rural areas of developing countries [27]. It may also indicate a general lack of possibilities for further training as part of continuing adult education [17]. The latter, as well as the fact that still a proportion of plant health problems may be diagnosed incorrectly (Figures 2 and 3), both demand further and regular refresher in-service trainings in adult education in agriculture.

## 5. Conclusions

In conclusion, our study proves the value of short in-service training of agricultural extension practitioners based on multiple modes of learning techniques with a high practical and application focus. We hope that decision-makers among the plant health system stakeholders will consider that investments into regularly repeated refresher trainings as part of a continuous professional education in agriculture are likely worth the value as better diagnoses can lead to more appropriate pest management advice, and may reduce wrong-targeted and unnecessary use of pesticides. This will ultimately increase the safety of growers and consumers and will reduce negative impacts of pesticides on the environment.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su151712956/s1>, Table S1: Curriculum of Plantwise training module 1 on field diagnosis and operation of plant clinics for growers.

**Author Contributions:** S.T. designed the study; C.N., W.O. and P.N. organized the training events of plant doctors that led to the collected data; C.N., E.C., P.N., D.N. and S.T. provided the plant doctor training that is assessed here; C.N., W.O., W.I. coordinated the study; S.T., C.N., E.C., P.N., D.N., W.I., D.M., P.B. and W.O. implemented the study; D.M. and P.B. assured quality; S.T. prepared the statistical analysis and result visualization; S.T. wrote the draft of the manuscript and all co-authors contributed to its finalization. All authors have read and agreed to the published version of the manuscript.

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**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Personal information of the studied plant doctors has been deleted prior to analyses, and no such information is presented in the manuscript.

**Data Availability Statement:** All data on the quality of diagnoses of plant health problems before and after training were anonymized and are available on request.

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