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Anticipating the effects of pesticides on farmworkers health based on real practices – The case of banana plantation

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Anticipating the effects of pesticides on farmworkers health based on real practices – the case of banana plantation

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Thesis long summary in Italian

A seguito della crescente evidenza degli impatti generati dall'esposizione ai fitofarmaci (e.g., evidenze mediche di correlazione tra esposizione e insorgenza della malattia; relativi studi di impatto ambientale), l'attenzione verso il tema degli impatti dell'uso di questi prodotti è andata via via crescendo. Accanto all'attenzione generata dalle questioni "ambientali" in senso ampio, si affianca la risonanza della questione in termini di opinione pubblica, anche in contesti pubblici riguardo la regolamentazione a livello europeo ed extra-europeo.

Nell'ambito di questo lavoro di ricerca, si è innanzitutto proceduto all'analisi della letteratura esistente sul tema della salute dei lavoratori esposti al rischio di contatto con i pesticidi al fine di definire la domanda generale di ricerca e le eventuali sotto-domande utili a rispondere alla prima. Questa analisi è stata preceduta da una fase definitoria del "glossario" dei termini utilizzati nella stesura dell'elaborato di tesi. Si è proceduto a fornire definizioni di cui, per semplicità, si riporta un estratto:

Pesticida. Ci sono diverse definizioni di un pesticida. Il Codice Internazionale di Organizzazione delle Nazioni Unite per l'Alimentazione e l'Agricoltura (FAO, 2003) definisce un pesticida come:

> "Qualsiasi sostanza o miscela di sostanze destinate alla prevenzione, alla distruzione o al controllo di eventuali parassiti, compresi i vettori di malattia umana o animale, di specie indesiderabili di piante o animali che causino danni a interruzione o durante l'interruzione della produzione, della trasformazione, dello stoccaggio, del trasporto o la commercializzazione di prodotti alimentari, prodotti agricoli, legname, prodotti di legno o mangimi, o sostanze che possono essere somministrate ad animali per il controllo di insetti, aracnidi o altri parassiti nei loro corpi o sui loro corpi. Il termine comprende le sostanze destinate ad essere utilizzate come regolatrici della crescita vegetale, defolianti, disinfettanti o agenti per tonificare la frutta o impedire la caduta prematura di frutta e sostanze applicate alle colture prima o dopo la raccolta per proteggere la merce dal degrado durante lo stoccaggio ed il trasporto ".

È evidente che un pesticida, così definito, è utilizzato per la varietà dei benefici che fornisce all'attività produttiva agricola. Nel fare questo, ci sono alcuni effetti indesiderati e indesiderati dell'uso di pesticidi che non possono essere ignorati (Jeyaratnam, 1990). Si è, quindi, proceduto all'analisi dei benefici (e.g., miglioramento della produttività, protezione dalle perdite di raccolto/riduzione delle rese, protezione delle colture dopo la raccolta, controllo delle malattie vettoriali, qualità del cibo) e dei pericoli (e.g., tossicità cronica ed acuta, avvelenamento intenzionale e non intenzionale) legati all'uso dei pesticidi. Riguardo la tossicità cronica si sono anche repertoriate (tramite analisi della letteratura) le differenti patologie legate all'esposizione ai pesticidi quali: cancro, effetti neurologici, effetti sull'apparato riproduttore, altri effetti quali, ad esempio, l'asma.

Esposizione. L'esposizione è un concetto ingannevolmente semplice, definito come contatto a un confine corporeo tra una persona e un stressor ambientale (biologico, chimico o fisico) nel tempo (Hoppin et al., 2006). Questa semplice definizione maschera il fatto che un'analisi quantitativa di esposizione richiede la raccolta e l'analisi di parametri multipli come la concentrazione e la durata dell'esposizione, nonché i fattori di esposizione che influenzano i tassi di contatto e quindi determinano la magnitudo dell'esposizione.

"Dose" è un termine preso in prestito dalla chimica. Si riferisce ai livelli di sostanza attiva misurati in un confine biologico.

"Concentrazione" è anch'esso un termine preso in prestito dalla chimica. È la quantità di pesticidi misurata in una massa o volume di un ambiente (Hoppin et al., 2006).

Per "tossicità" si intende una proprietà fisiologica o biologica che determina la capacità di una sostanza chimica di fare del male o di produrre lesioni a un organismo vivente, ad eccezione dei mezzi meccanici (FAO, 2003).

Dall'analisi della letteratura è emerso come l'esposizione ai pesticidi possa contemplare diverse modalità (quali l'inalazione, l'ingestione o l'assorbimento cutaneo) (Figura 1), differenti livelli di dose e vari periodi di tempo (Jeyaratnam, 1990) (Figura 2).

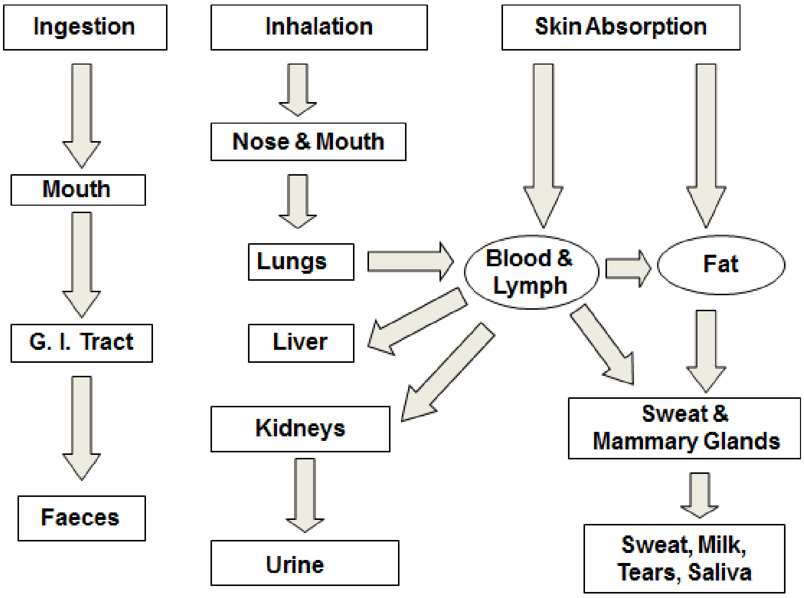

Figura 1 - Vari modi di esposizione ai pesticidi e loro percorso metabolico negli organi del corpo, fino alla loro escrezione (da Sharma and Goyal, 2014).

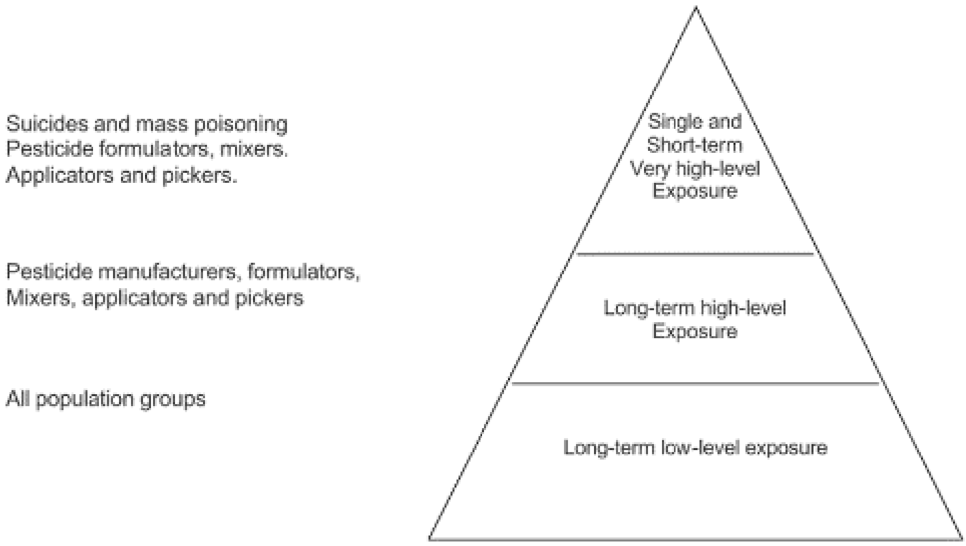

Figura 2 - Differenti popolazioni e differenti modalità di esposizione ai pesticidi

Sono state, inoltre, analizzate le principali occasioni di esposizione quali l'esposizione attraverso prodotti alimentari ed attraverso l'ambiente.

In un secondo momento, si è andati ad indagare quali fossero le popolazioni maggiormente esposte al rischio di contatto con i pesticidi (e, quindi, esposte al rischio delle conseguenze). I gruppi ad alto rischio esposti a pesticidi comprendono i lavoratori addetti alla produzione dei pesticidi, i formulatori, gli spruzzatori, i miscelatori, i caricatori ed i lavoratori agricoli. Nei settori industriali, i lavoratori hanno un rischio maggiore perché gestiscono molteplici prodotti chimici tossici, compresi i pesticidi, le materie prime, i solventi tossici e gli inerti.

Una seconda review della letteratura ha mirato ad analizzare quali siano le possibili soluzioni per la riduzione dell'esposizione ai pesticidi. Si è proceduto ad analizzare il ruolo dei differenti attori (e.g., i Governi, le Agenzie Internazionali, l'industria agro-chimica, i manager di piantagione), e le possibili soluzioni pratiche: dalla totale eliminazione dei pesticidi (non applicabile perché intaccherebbe significativamente le rese agricole con conseguente impatto sulla sussistenza alimentare del Pianeta) all'integrazione del controllo chimico (operato attraverso i pesticidi) con forme alternative di controllo (e.g., controllo genetico, biologico, biotecnico, colturale e fisico).

A questo punto è stata esplicitata la problematica della tesi: riprogettare i sistemi colturali per ridurre l'esposizione ai pesticidi. Si è, quindi, proceduto a precisare che un *sistema colturale* è definibile come:

"Un insieme di procedure di gestione applicate ad una data area trattata uniformemente, che può essere un campo, parte di un campo o di un gruppo di campi" (Sebillotte, 1990).

Questo comprende molte operazioni tecniche, ad esempio la scelta della sequenza di colture, la copertura delle colture, la cultivar, le pratiche di lavorazione, la data e la densità della semina, il tasso di fertilizzazione e il controllo dei parassiti chimici. Il termine "sistema" è usato qui perché queste scelte tecniche sono interdipendenti (Meynard et al., 2003).

I sistemi di coltivazione attuali (rotazioni corte, uso di varietà produttive, ma poche malattie, piantine ad alta densità e fecondazione elevata) sono strutturalmente dipendenti dai pesticidi. Nell'ambito di una protezione e produzione integrata, una riduzione significativa del loro utilizzo richiede un ripensamento della costruzione di questi sistemi, introducendo in combinazione diverse tecniche (ognuna con efficacia parziale) che consente la creazione di condizioni sfavorevoli per lo sviluppo di parassiti (Aubertot et al., 2005). Piuttosto che combattere la popolazione di parassiti quando già sviluppato, l'attenzione è sulla limitazione della crescita della popolazione stessa (Lucas 2009). Le diverse strategie evocate prima devono essere combinate. Mentre il controllo chimico è una soluzione "omogenea" (per ogni problema abbiamo una sola soluzione chimica), non esiste una combinazione di tecniche uniche che sarebbero adattate a tutti gli impianti di piantagione (Meynard, 2008; Meynard e Girardin, 1991). Le combinazioni di pratiche devono essere adattate in ogni situazione di produzione (Aubertot and Robin, 2013).

Quando non è possibile rinunciare all'uso di pesticidi, è comunque possibile attenuare l'esposizione dei lavoratori ai pesticidi. Le misure derivano da semplici pratiche di gestione alla completa riprogettazione del sistema di coltivazione.

L'esposizione può essere attenuata tramite pratiche di gestione semplici: nel campo del lavoro, il manager della piantagione può decidere di assemblare squadre di lavoratori addestrati per la manipolazione di pesticidi. Se il manager vuole operare a livello aziendale, può organizzare corsi di formazione sulle pratiche di manipolazione dei pesticidi e sui rischi sanitari legati a pesticidi destinati a tutti i lavoratori della società. Può anche decidere di subappaltare l'applicazione di questi ad un fornitore di servizi. In questo modo, egli è sollevato dal dover fornire gli strumenti per proteggere gli operatori (ad esempio l'acquisto di Dispositivi di Protezione Individuale e la messa in atto di politiche agli operatori per incentivarli ad indossarli).

Nello stato attuale della conoscenza dobbiamo riconoscere che non è sempre possibile rinunciare ai pesticidi. Ciononostante, si assume l'ipotesi che sia possibile ridurre l'uso dei pesticidi nell'agricoltura e/o ridurre l'esposizione dei lavoratori senza crollare il sistema riconquistando i sistemi culturali. È quindi possibile "ridisegnare i sistemi di coltivazione per ridurre l'esposizione ai pesticidi". L'idea è di ridisegnare il sistema di coltivazione in relazione al potenziale danno causato alla salute dei lavoratori. Per raggiungere questo obiettivo, è necessario essere in grado di separare tra sistemi di coltivazione diversi a seconda di questo criterio (potenziali danni alla salute dei lavoratori a causa di pesticidi). La necessità di discriminazione tra i sistemi di coltivazione è la ragione che giustifica la nostra domanda di ricerca generale:

Domanda di ricerca generale: "Come discriminare tra i possibili sistemi di coltivazione in relazione agli effetti dei pesticidi utilizzati sulla salute dei lavoratori agricoli?"

La domanda generale di ricerca sottende la necessità di dover esplorare le seguenti *sub-questions*:

Come classificare i diversi sistemi di coltivazione?

Qual è il legame tra il sistema colturale e le variazioni di esposizione?

Quali sono i metodi attuali per valutare la salute dei lavoratori agricoli?

Come riportato in letteratura, la disponibilità di un indicatore di rischio legato ai pesticidi che sia semplice, ma affidabile sarebbe particolarmente rilevante (Feola et al., 2011). Il risultato atteso è quello di preparare la strada per costruire uno strumento di supporto alle decisioni che permetta ai manager di piantagione di discriminare tra i vari sistemi di coltivazione rispetto al criterio del danno sulla salute degli agricoltori causato dall'esposizione ai pesticidi. Le caratteristiche principali di questo nuovo strumento saranno le seguenti: i) tener conto delle pratiche reali attuate dai lavoratori agricoli (ivi comprese le "cattive" pratiche); ii) semplicità di raccolta dei dati; iii) rapida elaborazione dei dati.

Lo strumento potrà essere utilizzato per valutare le conseguenze delle modifiche sia nel programma annuale che nel ciclo pluriennale di una nuova pianta/piantagione. Questa valutazione potrà essere eseguita sia per ettaro o per parcella, sia per tutta la superficie del raccolto a livello aziendale. Sarà possibile valutare la variazione della tecnica di applicazione e/o la variazione del sistema di coltivazione. Lo strumento sarà progettato sia per la valutazione di sistemi esistenti di coltivazione (utilizzo ex post), sia per la valutazione di nuovi sistemi di coltivazione pianificati (utilizzo ex ante).

Le tre sub-domande derivano dalla domanda generale di ricerca.

Sono state analizzate, in questa fase, le principali variazioni operabili all'interno di un sistema di coltura: la variazione di prodotto (con relativa variazione della tossicità a cui i lavoratori sono esposti); la variazione della tecnica di applicazione del prodotto/mistura (legata alla possibilità di variazione della via di esposizione: per esempio dall'inalazione al contatto); le variazioni nel sistema di coltura (e.g., l'introduzione di "piante di servizio" tra gli alberi che riducono la necessità di uso degli erbicidi).

Le principali metodologie utilizzate attualmente per valutare l'esposizione ai pesticidi e gli impatti sulla salute umana sono: l'analisi del ciclo di vita ambientale (Environmental Life Cycle Assessment – ELCA) e la valutazione del rischio (Risk Assessment – RA).

Di entrambe le metodologie sono stati presi in esame i metodi più diffusi, analizzandone le modalità di calcolo e la loro capacità di rispondere alla nostra domanda di ricerca. Entrambe le metodologie si sono dimostrate inadatte a rispondere alla nostra problematica. Infatti, dalla review della letteratura emerge come i metodi attuali non siano parzialmente in grado di gestire la questione dei cambiamenti di prodotto, o saranno in grado di farlo quando i database saranno più documentati.

In sostanza emerge una mancanza di metodi che valutino le variazioni del sistema di applicazione e nel sistema di coltivazione. Nessun metodo attuale è in grado di valutare in modo equo entrambi i tipi di cambiamenti. La causa è il profondo divario nella conoscenza scientifica riguardo agli effetti dell'applicazione dei pesticidi e agli effetti dei cambiamenti nei sistemi di coltivazione, sulla salute umana.

Dalle review della letteratura emerge un divario relativo alla valutazione delle pratiche reali. Quando vengono valutate le pratiche reali, lo studio è correlato all'utilizzo in uno specifico contesto di un'unica sostanza. È quindi impossibile generalizzarne i risultati. Per questi motivi, il nostro contributo è quello di sviluppare un metodo sensibile alle modifiche dei prodotti, dei sistemi di applicazione e coltivazione, valutando le pratiche reali degli operatori e dei lavoratori esposti. Come evidenziato sopra, il divario nella conoscenza è ampio e profondo. I manager devono prendere decisioni in un contesto in cui "le incertezze del sistema o la partecipazione alle decisioni (o entrambe) sono elevate" (Funtowicz and Ravetz, 1994). Ci troviamo di fronte a "imprevedibilità, controllo incompleto e pluralità di prospettive legittime" (Funtowicz and Ravetz, 1994). In un contesto di questo tipo è necessario ricorrere all'elicitazione degli esperti. Infatti, l'idea è che le esperienze degli esperti comprendano (e possano supportare) tutto il complesso sistema di relazioni incorporato nella questione. Cerchiamo di sostituire la scienza incompleta con esperienze esperte. Poiché necessitavamo di elicitare concretamente gli esperti, è stato necessario ridurre il campo in cui raccogliere le loro esperienze. In questo lavoro di ricerca scegliamo, quindi, di concentrarci sulla coltivazione della banana.

Si è provveduto, quindi, a fornire un quadro completo della coltivazione e del mercato della banana destinata all'esportazione.

Dalla revisione della letteratura è emerso come sia necessario costruire un metodo in grado di discriminare tra i diversi sistemi di produzione, sulla base dei potenziali impatti sulla salute degli operatori, basati sulle pratiche reali implementate nelle piantagioni.

Per far ciò, la nostra ricerca risponderà alle seguenti tre domande di ricerca:

Come è possibile raccogliere informazioni sulle pratiche reali attuate nella piantagione?

Come è possibile rappresentare le informazioni raccolte?

Come è possibile elaborare un indicatore tenendo conto delle pratiche reali messe in atto nella piantagione?

È stato, quindi, approfondito il posizionamento epistemologico interpretativista del lavoro, giustificando il suddetto posizionamento a scapito degli approcci post-positivisti e costruttivisti.

Sulla base della revisione della letteratura, poiché i metodi attuali (E-LCA e RA) non consentono di tenere conto delle pratiche reali, proponiamo un modello che tenga conto delle pratiche stesse e che sia utilizzabile per anticipare gli impatti futuri.

Il lavoro è basato sull'esperienza, che afferma come in alcune particolari condizioni di lavoro (ad esempio il calore e l'umidità) il rischio di esposizione diventa molto forte, e.g. per l'uso improprio dei Dispositivi di Protezione Individuale (DPI). Gli esperti sono stati sollecitati su questo argomento attraverso un metodo di consenso chiamato "*Delphi Expert Consensus Method*" (Jorm, 2015). Le informazioni raccolte sono state rappresentate attraverso degli alberi di conoscenza. Si è poi proceduto nel testare i nostri alberi attraverso l'osservazione di un vero e proprio studio di casi (durante il 3° anno del Dottorato). Con le informazioni raccolte sia dagli esperti sia dal caso studio, siamo stati in grado di elaborare un indicatore, utilizzabile dai manager delle piantagioni per valutare i sistemi di produzione attuati e le conseguenze di eventuali modifiche (ad esempio, nel tipo di prodotto utilizzato, pratiche di piantagione, organizzazione del lavoro).

In una prima fase il pool di esperti è stato selezionato scegliendo persone che avessero esperienza diretta riguardo le pratiche reali attuate nelle piantagioni di banane. Il pool era composto da: agronomi, economisti ed esperti di salute sul lavoro. Tutti gli esperti sono stati intervistati separatamente e in modo anonimo. Tutti gli esperti intervistati sono impiegati in un'organizzazione indipendente che si occupa di miglioramenti delle pratiche agricole ed ambientali. Le informazioni raccolte dall'esperienza sono state organizzate in 9 alberi di conoscenza (Figura 3) (Huosong et al., 2003; Marceau, 2007; Yager, 2006).

In questo studio, i diversi sistemi di produzione di banane sono stati suddivisi nelle nove fasi della coltivazione della banana per la durata di una piantagione. Così sono stati costruiti nove alberi di conoscenza corrispondenti alle principali fasi della coltivazione della banana:

1. Distruzione della vecchia piantagione
2. Terreno incolto
3. Accrescimento in serra
4. Accrescimento all'aperto
5. Fertilizzazione
6. Diserbo

7. Protezione delle piante (dalla *Black Sigatoka* e dai nematodi)

8. Cura del casco

9. Trattamenti post-raccolta (nell'impianto di confezionamento)

Abbiamo strutturato gli alberi per individuare le diverse alternative relative alle tre principali occasioni di esposizione per gli operatori: preparazione della miscela di pesticidi, applicazione di pesticidi e pulizia delle apparecchiature (incluso il trattamento dei reflui della miscela di pesticidi), e per gli altri lavoratori agricoli (quando presenti nelle parcelle trattate e quando non viene rispettato il tempo di sospensione legale dopo un trattamento).

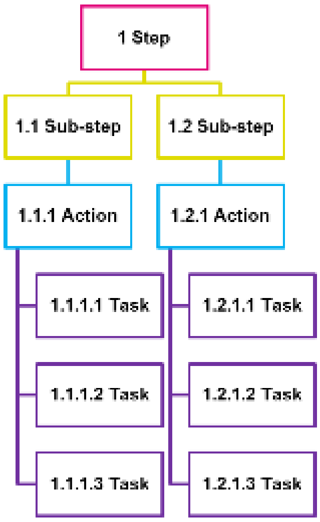

Figura 3 - Struttura degli alberi di conoscenza

Abbiamo organizzato i grafici in modo cronologico: prima sono stati individuati i diversi step che compongono un sistema di produzione di banane. Per ciascuno di essi sono stati evidenziati i sub-step da attuare. Quindi abbiamo identificato le azioni operative alternative per eseguire ogni sub-step, tra i quali la scelta può essere operata. Infine ogni azione implica che si svolgano tre attività (task) (ove vi è, potenzialmente, esposizione ai pesticidi): la preparazione, l'applicazione e la pulizia degli strumenti.

Le pratiche reali riguardanti tutti questi fattori sono presi in considerazione dagli esperti, quando ritengono che tale o tale compito sia eseguito con un tale livello di esposizione.

Inoltre, le interviste agli esperti evidenziano quali siano i criteri pertinenti che ci permettono di progettare i diversi rami del knowledge tree. I criteri pertinenti che creano biforcazioni tra i diversi rami sono: i metodi di applicazione e le "politiche PPE”[1]. Infatti, nei diagrammi di flusso

[1] La traduzione inglese di Dispositivi di Protezione Individuale (DPI) è *Personal Protective Equipment (PPE)*.

è stata inclusa la presenza (o meno) delle "politiche PPE". Noi chiamiamo "politiche PPE" le iniziative che il manager di piantagione mette in atto per incoraggiare gli operatori a indossare le PPE. Di solito si tratta di corsi di formazione riguardo al rischio legato ai pesticidi e all'uso dei DPI, o pagamenti bonus (normalmente salariali). Dalle interviste emerge l'idea che l'implementazione di queste politiche influenzi l'esposizione dell'operatore durante l'attività di applicazione.

Questi alberi di conoscenza ci hanno permesso di disegnare degli alberi di decisione.

Mentre i *knowledge trees* contengono informazioni sulle operazioni che possono avvenire insieme nello stesso step (ad es., il trattamento con fungicidi e il trattamento per i nematodi durante la fase di "protezione delle piante"), gli alberi decisionali contengono solo rami esclusivi l'uno dell'altro (ad esempio il trattamento con fungicidi può essere condotto attraverso trattamento con aereo/elicottero o tramite atomizzatore a dorso).

L'obiettivo perseguito con l'elaborazione di alberi decisionali è quello di organizzare le informazioni necessarie per calcolare l'indicatore, ma soprattutto in previsione di una eventuale informatizzazione delle conoscenze raccolte dagli esperti.

Noi ipotizziamo che possiamo "stimare" il costo umano del pesticida per l'operatore medio addizionando i costi umani dei pesticidi dei compiti in cui è investito.

Il costo umano dei pesticidi di una task per l'operatore medio è proporzionale al numero di operatori che eseguono l'attività, al numero di eventi, al grado di esposizione dell'operatore medio e alla tossicità. I dati necessari per calcolare il costo umano di una task sono:

- il numero di operatori che svolgono il compito;
- il numero di ripetizioni dell'attività, che dipende dal numero di ripetizioni del trattamento in questione. Riteniamo che ogni azione indichi i tre compiti "preparazione, applicazione, pulizia", ma questi potrebbero non riguardare lo stesso numero di operatori e saranno calcolati separatamente;
- il grado di esposizione dell'operatore medio indicato dagli esperti, per questa parte del sistema di produzione e per questa modalità di trattamento, indicato nell'albero di decisione;

- la tossicità del prodotto. Si consiglia di utilizzare l'inverso (1 / AOEL) dell'*Acceptable Operator Exposure Level (AOEL)* (espresso in mg del prodotto per kg di peso corporeo al giorno) del prodotto in esame.

L'indicatore che rappresenta l'attuazione di un'azione composta dalle tre attività correlate (preparazione, applicazione, pulizia) può essere espressa così:

$$Human\ cost_{operators} for\ one\ action = \left(\sum_{j=1}^{3} k_j T_j w_j \frac{1}{AOEL_j} \right)$$

dove:

- j rappresenta uno dei tre compiti: preparazione, applicazione o pulizia.
- k_j rappresenta il numero di operatori coinvolti in questa attività.
- T_j indica il numero di volte in cui l'attività viene ripetuta, alle stesse condizioni, sul perimetro del calcolo spazio-tempo.
- w_j riflette il grado di esposizione dell'operatore ed è stato individuato negli alberi delle conoscenze basati su un compito specifico in un punto specifico del sistema di produzione.
- $AOEL_j$ identifica l'AOEL del prodotto utilizzato nella task j.

Implementazione del caso studio

La salute dei lavoratori può essere influenzata in modi diversi e per ragioni connesse con l'esposizione a sostanze chimiche sul luogo di lavoro, ma potrebbe anche essere indipendente da questa. In particolare, non abbiamo creato i nostri alberi e l'indicatore tenendo conto dell'esposizione generale a prodotti chimici (e.g., esposizione a prodotti per la pulizia, come candeggina e detergenti). Allo stesso modo, non teniamo conto di patologie che non derivano direttamente dall'esposizione di pesticidi sul posto di lavoro (ad esempio, patologie muscolo-scheletriche, disturbi genetici preesistenti). Non abbiamo neanche considerato l'impatto dovuto all'esposizione in un contesto domestico (ad esempio, durante il giardinaggio). Quindi, il nostro studio riguarda solo gli impatti causati dall'esposizione professionale degli operatori ai pesticidi, nel caso di piantagioni di banane da dessert coltivate solo per l'esportazione.

Il test mirava a controllare le difficoltà che il *practitioner* può affrontare nel tentativo di valutare il proprio sistema di produzione applicando il metodo sopra descritto. In questo lavoro di ricerca vogliamo definire un metodo semplice da implementare e che possa essere utilizzato con successo dai manager delle piantagioni, con una semplice raccolta dati ed una rapida implementazione.

In dettaglio, il test di fattibilità mirava a:

- individuare un dato sistema di produzione attuato in un caso reale, tra i sistemi di produzione descritti dagli alberi di conoscenza. Il test tenta di rispondere alla seguente domanda: possiamo identificare in modo rapido e facilmente un dato sistema di produzione reale dalla combinazione degli alberi di conoscenza? Questa identificazione ci consente di conoscere il w_j di ciascuna delle attività implementate.
- verificare se gli altri dati necessari per il calcolo dell'indicatore siano semplici, o meno, da raccogliere sulla piantagione.
- verificare se possiamo trovare facilmente alternative per migliorare il sistema produttivo o per aiutare a progettare nuovi sistemi produttivi.

Dopo aver ottenuto e interpretato i risultati del calcolo dell'indicatore "costo umano", abbiamo proposto miglioramenti del metodo.

Il luogo di implementazione del caso studio è stato la Repubblica Dominicana. Si è quindi provveduto a studiare il contesto specifico considerato, analizzando in via preventiva il contesto storico della coltivazione di banana nel Paese, il ruolo primario che essa riveste nell'economia nazionale, la struttura delle piantagioni, i problemi sociali ad esse connessi (e.g., il flusso di immigrati da Haiti destinati al lavoro in piantagione).

Sono state condotte quattro interviste semi-strutturate a quattro manager di piantagione che si sono resi disponibili ad essere intervistati.

Sono state individuate quattro persone disponibili ad essere intervistate (I1, I2, I3 e I4), dove I1 e I2 si riferiscono a grandi piantagioni, e I3, 14 si riferiscono a piccole piantagioni.

Le quattro persone intervistate erano: un proprietario di piantagione (I1), un presidente di azienda proprietaria di una piantagione (I2), un caposquadra di una piantagione (I3) e un supervisore di piantagione (I4). I3 è stato supportato dal supervisore tecnico dell'associazione dei produttori per rispondere alle nostre domande.

Le interviste sono state condotte usando un traduttore dall'inglese/francese allo spagnolo. Ogni intervista è durata in media 2 ore. Le sedi delle interviste sono state: la casa di un proprietario della piantagione (I1); la sede centrale della società proprietaria della piantagione, situata accanto alla piantagione stessa (I2); l'impianto di confezionamento (I3); l'area all'ingresso della piantagione (I4).

Le interviste sono state suddivise in cinque parti:

1. Introduzione, composta da nove domande. In questa prima parte abbiamo raccolto informazioni generali sulla piantagione e sulla persona intervistata, come il suo ruolo nella piantagione (lui/lei era il proprietario della piantagione o solo un lavoratore dipendente?). L'estensione, l'età della piantagione, quanti lavoratori fossero impiegati nella piantagione e se il produttore facesse parte di un'associazione di produttori.

2. Informazioni particolareggiate sulla piantagione. Questa sezione era costituita da sedici domande. In questa sezione, abbiamo indagato in maniera più approfondita chi fosse il proprietario della terra, che prodotti venissero coltivati in quel terreno (solo banane o no? Questo era molto importante per la nostra problematica a causa delle quantità e delle tipologie di prodotti chimici utilizzati) e se le banane coltivate in quella piantagione fossero destinate, o meno, all'esportazione. In questa parte, abbiamo raccolto informazioni anche sull'attuazione delle pratiche generali di coltivazione, controllando che fossero comprese e tracciabili nei nostri alberi di conoscenza. è stato indagato, ad esempio, se un fornitore di servizi fosse utilizzato per fare applicazione di pesticidi, ed in quali fasi, e la presenza di una "squadra" per l'applicazione dei prodotti chimici direttamente selezionata tra i lavoratori delle piantagioni (gli operatori) e da quanti elementi fosse composta questa squadra. Se presenti (sia il fornitore di servizi, sia il "team"), in quale fase venissero utilizzati, e per quante volte l'anno. In particolare, per il "team" vi è stata una domanda su quale tipo di DPI utilizzino (stivali, tuta, occhiali, ecc.).

   Ci sono state domande sulle pratiche generali applicate nella piantagione, ad es. se esistesse un luogo specifico in cui i prodotti fitosanitari sono immagazzinati, se esistesse un luogo specifico in cui i DPI non ancora utilizzati fossero conservati, dove gli operatori potessero riporre i propri vestiti quando indossano i DPI, se vi fosse un processo di gestione dei DPI usati (ad esempio, vengono stoccati da qualche parte? Sono smaltiti da qualche parte? Sono riutilizzati?).

   Al termine di questa sezione, abbiamo raccolto informazioni su:

- le "politiche PPE": se venissero organizzati corsi di formazione per la nocività dei pesticidi e/o malattie legate al contatto con essi o se venissero versati bonus/pagamenti in contanti agli operatori incentivando l'indossare i DPI
- i gesti tecnici per la protezione degli impianti (defogliazione, ecc.) che possono evitare o ridurre l'uso di sostanze chimiche
- il ruolo dell'associazione di produttori (se il produttore fa parte di un'associazione) nelle attività legate ai pesticidi (ad esempio formazione, acquisti collettivi, ecc.).

3. Nella terza parte, abbiamo studiato quale delle fasi della piantagione da noi individuate, siano implementate in un ciclo colturale. Per gli step principali, abbiamo raccolto informazioni sui prodotti utilizzati, sulla frequenza del trattamento e sulle attività.

   Alla fine di questa sezione abbiamo esaminato quali sono i metodi di preparazione della miscela e quali sono i metodi adottati per applicare i diversi pesticidi.

4. La quarta sezione riguarda informazioni sull'attività di pulizia degli strumenti. Le informazioni su questo compito non sono state raccolte dagli esperti perché essi hanno dichiarato di non averne avuto esperienza durante la loro carriera. Abbiamo esaminato la presenza o meno di una fase di pulizia dello strumento, con quale frequenza è effettuata e da chi, il luogo e, infine, la presenza di processi di gestione delle acque reflue.

5. L'ultima parte della guida dell'intervista conteneva le domande per i lavoratori delle piantagioni, circa il loro livello di alfabetizzazione, l'uso dei DPI, eventuali ragioni che li portano a non usarli, ore di lavoro, rispetto del tempo di sospensione dopo un trattamento.

Le interviste sono state integralmente trascritte ed analizzate secondo quanto previsto dagli obiettivi del test.

Sulla base di quanti riportato nelle interviste ai manager di piantagione, alcune piccole modifiche sono state apportate agli alberi sia di conoscenza, che di decisione.

Implicazioni del lavoro

Nell'ultimo capitolo dell'elaborato, si è provveduto ad inserire il presente lavoro di ricerca nell'ambito delle già diffuse metodologie per la valutazione degli impatti sociali e socioeconomici di una produzione. In particolare, si è provveduto ad approfondire le tematiche legate alla Social Life Assessment (S-LCA).

Come riportato da Macombe (2017), i principali usi di S-LCA sono:

• fornire conoscenze su alcune delle principali conseguenze del cambiamento (quali sono i principali impatti principali in termini di salute pubblica e in termini di salute dei lavoratori coinvolti);

• assistenza per il coordinamento degli attori (ad esempio, come base per le discussioni sulla configurazione del progetto);

• influenzare la decisione sui progetti futuri. Gli studi derivanti dalla S-LCA evidenziano i principali problemi sociali e le richieste di cambiamenti nel presente progetto che possono essere marginali dal punto di vista tecnico, ma molto importanti dal punto di vista sociale;

• contribuendo a mettere a punto il lato sociale dei progetti. S-LCA riempie il lato sociale dei progetti, riportando diversi aspetti sociali (previsti e inattesi) e richiedendo modifiche quando necessario;

• generare innovazioni guidate da considerazioni sociali (ad esempio mitigando gli impatti sulla salute dei pesticidi, come in questo specifico lavoro).

Tra il 2005 e il 2008, l'Organizzazione mondiale della sanità ha deciso di istituire una "Commissione dei determinanti sociali della salute" (CSDH), incaricata di spiegare i rapporti tra salute della popolazione / famiglie e molti altri fattori (ad esempio diritti fondiari, lavoro dignitoso, corruzione ecc.). Lo scopo era quello di riconoscere ufficialmente i legami tra condizioni sociali e salute rilevanti, al fine di consigliare i responsabili politici per politiche sanitarie (inter settoriali) sane.

Nel rapporto del CSDH (WHO, 2009), gli autori hanno suddiviso i determinanti sociali in due scale:

• la scala "macro" di uno stato, o una regione di grandi dimensioni, nei paesi in via di sviluppo,

• la scala "meso" di un gruppo di famiglie rurali, nelle regioni rurali dei paesi in via di sviluppo.

Il presente lavoro mira a incoraggiare un lavoro dignitoso attraverso l'identificazione di possibili scelte meno dannose per la salute e la garanzia di ambiente e sicurezza salubri. Il risultato di questo intero lavoro di tesi è formalizzato in un *pathway* in scala meso, chiamata "Wesseling *pathway*".

Questo *pathway* può essere dettagliata rappresentando la catena causa-effetto tra operazioni di coltivazione e tossicità acuta. Questa può essere rappresentata come divisa in tre parti:

1. Pianificazione. In questa fase il decisore (ad esempio, direttore delle piantagioni, consulente) decide quali passi di produzione devono essere effettuati per ottenere il prodotto agricolo desiderato (ad esempio, un prodotto con: un calibro richiesto, particolari caratteristiche fisiche, senza segni di nascita di presenza di organismi nocivi). In funzione del prodotto desiderato, imposta anche le sotto-fasi e le azioni e le modalità per eseguirle in termini di:

    a. Necessità o no dell'applicazione di pesticidi.

    b. Tipo di prodotto (chimico o non) che deve essere applicato.

    c. Numero di ripetizioni dell'applicazione (questo numero può essere modificato a causa di eventi imprevisti, come condizioni meteorologiche insolite).

    d. Necessità o meno della preparazione delle condizioni al contorno, quali per esempio: : strumenti da utilizzare nella preparazione della miscela (ad esempio, serbatoi di miscelazione), luogo in cui deve avvenire la preparazione, chi è incaricato di svolgere questo compito.

    e. Determinazione delle condizioni di applicazione, in termini di: particolari strumenti da utilizzare nell'applicazione di pesticidi (ad esempio, aereo, quadrupolo, irroratore a zaino). In questa parte, il decisore può anche pianificare l'organizzazione del lavoro nella piantagione (ad es. Creazione di gruppi di applicazione di lavoratori interamente o principalmente dedicati all'applicazione di pesticidi).

    f. Determinazione delle condizioni di pulizia dello strumento, in termini di: strumenti da utilizzare per la pulizia (ad es. strumenti particolari), luogo in cui deve avvenire la pulizia, chi è incaricato di svolgere questo compito.

2. Attuazione. In questa seconda fase c'è lo svolgimento concreto dei diversi compiti. È in questa fase che le condizioni avverse (ad esempio calore, umidità, pendenza) possono

influenzare ciò che è stato prescritto nella prima fase. Nella fase di implementazione osserviamo anche l'uso, o meno, dei DPI e, più in generale, delle cattive pratiche.

3. Conseguenze. In questa fase osserviamo l'esposizione correlata e le conseguenze in termini di tossicità acuta. Evidenziamo come questa sia l'unica fase in cui il decisore non ha alcun potere di intervento.

Per quanto riguarda le prospettive del presente lavoro, queste riguardano lo sviluppo dell'indicatore proposto al fine di valutare la multi-esposizione ai fitofarmaci, sia in termini di esposizione ripetuta nel tempo allo stesso prodotto, sia di esposizione a più prodotti nello stesso momento. In secondo luogo, l'indicatore di "costo umano" può essere sviluppato anche per i lavoratori agricoli generici (coloro che non sono preposti all'applicazione dei fitofarmaci, ma che si trovano, in ogni caso, esposti a causa dell'applicazione fatta da altri) e per i residenti nelle adiacenze dei siti di produzione agricola. L'indicatore può, inoltre, essere sviluppato per altre fasi del ciclo di vita del fitofarmaco (e.g., la fase di produzione) al fine di fornire una prospettiva ampia in fase di *decision making*, soprattutto per le eventuali decisioni a livello di *policies* pubbliche.

Il presente indicatore è stato sviluppato prendendo in considerazione il solo caso della produzione di banana per l'esportazione. In futuro sarà possibile lavorare ad un adattamento ad altre colture, tenendo conto delle relative specificità.

Gli autori, inoltre, ritengono utile lo sviluppo di casi studio di comparazione tra produzione agricola convenzionale e produzioni agricole che hanno ottenuto un'etichettatura di natura sociale. Dall'osservazione del contesto e da alcune testimonianze documentate anche in letteratura, non si ritiene sia scontato l'ottenimento di un risultato favorevole per una produzione con etichetta che testimoni una produzione volta al miglioramento delle condizioni dei lavoratori.

Infine, gli autori consigliano l'uso di approcci partecipativi nell'ambito dell'ideazione di sistemi di coltura innovativi e nello sviluppo di casi studio attraverso l'utilizzo della metodologia Social Life Cycle Assessment (S-LCA).

Thesis long summary in French

Suite aux preuves croissantes des impacts générés par l'exposition aux produits phytopharmaceutiques (par exemple, preuve médicale de corrélation entre l'exposition et l'apparition de la maladie, études connexes de l'impact environnemental), l'attention portée au sujet des impacts de l'utilisation de ces produits a grandi progressivement. À côté de l'attention générée par les questions « environnementales » au sens large, il y a aussi la résonance de la question en termes d'opinion publique, même dans les contextes publics concernant la régulation au niveau européen et extra-européen.

Dans le cadre de ce travail de recherche, nous avons d'abord procédé à l'analyse de la littérature existante sur la santé des travailleurs exposés au risque de contact avec des pesticides afin de définir la question générale de recherche et les sous-questions utiles à répondez à la première. Cette analyse a été réalisée à partir d'une phase définitoire du « glossaire » des termes utilisés dans la rédaction de la thèse. Nous avons procédé à fournir des définitions dont, pour simplifier, nous rapportons un extrait:

Pesticide. Il existe différentes définitions de pesticide. Le Code de l'Organisation internationale des Nations Unies pour l'alimentation et l'agriculture (FAO, 2003) définit un pesticide comme suit:

"Toute substance ou mélange de substances destiné à la prévention, la destruction ou la lutte contre tous organisme nuisible, y compris les vecteurs de maladies humaines ou animales, d'espèces végétales ou animales indésirables qui causent des dommages à l'interruption de la production, transformation, stockage, transport ou commercialisation d'aliments, de produits agricoles, de bois, ou d'aliments pour animaux ou de substances pouvant être administrées aux animaux pour lutter contre les insectes, les arachnides ou d'autres parasites dans leur corps ou sur leur corps Le terme comprend les substances destinées à être utilisées comme régulateur de croissance, défoliant, désinfectant ou agent pour tonifier les fruits ou empêcher la chute prématurée des fruits et des substances appliqués aux cultures avant ou après la récolte pour protéger les marchandises de la dégradation pendant le stockage et transport ".

Il est évident qu'un pesticide, tel que défini, est utilisé pour la variété des avantages qu'il procure à l'humanité. Ce faisant, certains effets indésirables de l'utilisation des pesticides ne peuvent pas être ignorés (Jeyaratnam, 1990). Nous avons ensuite procédé à l'analyse des avantages (e.g., amélioration de la productivité, protection contre les pertes de récolte / réduction du rendement, protection des cultures après la récolte, contrôle des maladies vectorielles, qualité des aliments) et dangers (e.g., toxicité chronique et aiguë, intoxication intentionnelle et non intentionnelle) liée à l'utilisation de pesticides. Concernant la toxicité chronique, les différentes pathologies liées à l'exposition aux pesticides ont également été rapportées (par des analyses bibliographiques) telles que: cancer, effets neurologiques, effets sur le système reproducteur, autres effets tels que, par exemple, l'asthme.

Exposition. L'exposition est un concept faussement simple, défini comme la mise en contact d'une frontière corporelle entre une personne et un facteur de stress environnemental (biologique, chimique ou physique) au fil du temps (Hoppin et al., 2006). Cette définition simple masque le fait qu'une analyse quantitative de l'exposition nécessite la collecte et l'analyse de paramètres multiples tels que la concentration et la durée d'exposition, ainsi que des facteurs d'exposition qui influencent les taux de contact et déterminent l'ampleur de l'exposition.

"Dose" est un terme emprunté de la chimie. Il se réfère aux niveaux de substance active mesurés dans une limite biologique.

La "concentration" est aussi un terme emprunté de la chimie. C'est la quantité de pesticides mesurée dans une masse ou un volume d'un environnement (Hoppin et al., 2006).

« Toxicité » désigne une propriété physiologique ou biologique qui détermine la capacité d'un produit chimique à nuire ou à causer des dommages à un organisme vivant, à l'exception des moyens mécaniques (FAO, 2003).

L'analyse de la littérature a révélé que l'exposition aux pesticides peut inclure différentes modalités (telles que l'inhalation, l'ingestion ou l'absorption cutanée) (Figure 1), différents niveaux de dose et différentes périodes (Jeyaratnam, 1990) (Figure 2).

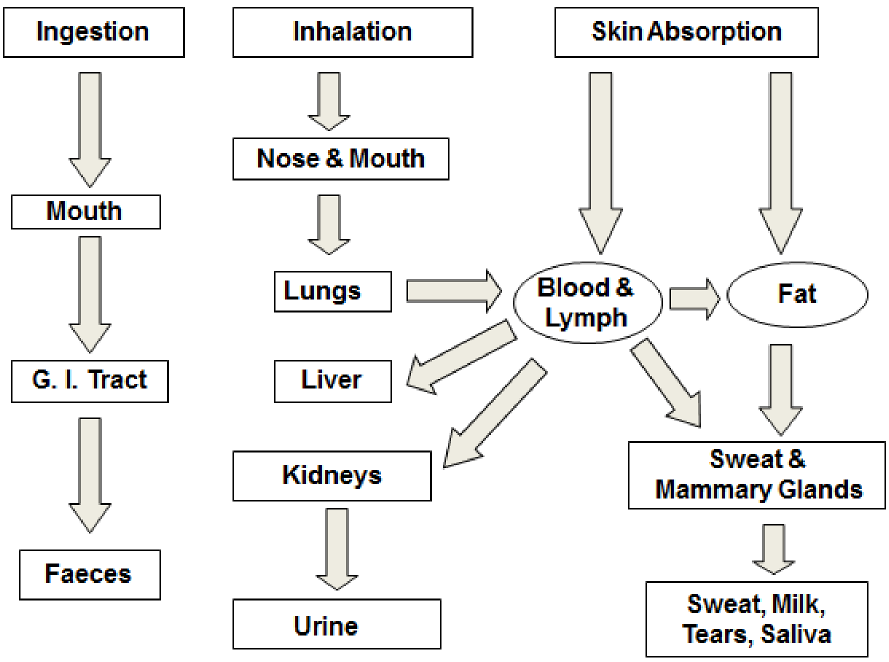

Figure 1 - Différentes voies d'exposition aux pesticides et leur voie métabolique dans les organes du corps, jusqu'à leur excrétion (de Sharma et Goyal, 2014).

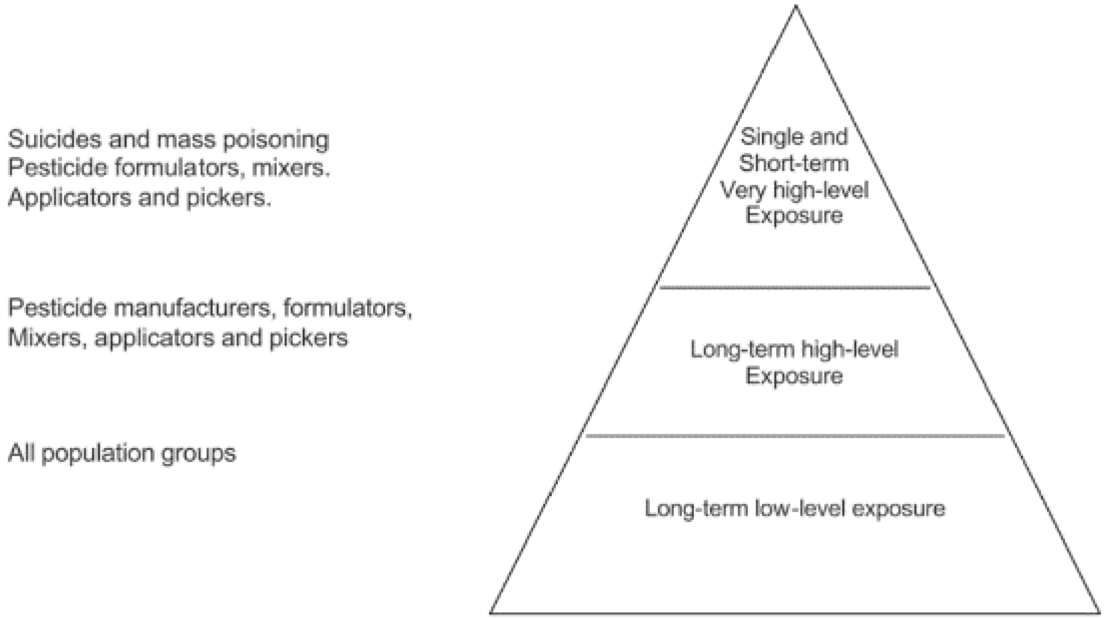

Figure 2 - Différentes populations et différentes méthodes d'exposition aux pesticides

Les principales opportunités d'exposition, telles que l'exposition à travers les produits alimentaires et à travers l'environnement, ont également été analysées.

Dans un second temps, nous sommes allés enquêter sur les populations les plus exposées au risque de contact avec les pesticides (et donc exposées au risque de conséquences). Les groupes à haut risque exposés aux pesticides comprennent : les travailleurs des pesticides, les formulateurs, les applicateurs, les mélangeurs, les chargeurs et les travailleurs agricoles. Pendant la production et la formulation, le danger est plus élevé car les processus impliqués ne sont pas sans risque. Dans les secteurs industriels, les travailleurs sont plus à risque car ils gèrent de multiples produits chimiques toxiques, notamment les pesticides, les matières premières, les solvants toxiques et les matériaux inertes.

Une deuxième revue de la littérature visait à analyser les solutions possibles pour la réduction de l'exposition aux pesticides. Le rôle des différents acteurs (par exemple, les gouvernements, les agences internationales, l'industrie agro-chimique, les gestionnaires de plantations) a été analysé, et des solutions pratiques possibles: de l'élimination totale des pesticides à l'intégration du contrôle chimique (opéré à travers les pesticides) avec des formes alternatives de contrôle (e.g., génétique, biologique, biotechnique, contrôle culturel et physique).

À ce stade, la problématique de la thèse a été expliquée: repenser les systèmes de culture pour réduire l'exposition aux pesticides. Nous avons donc précisé qu'un système de culture peut être défini comme:

"Un ensemble de procédures de gestion appliquées à une zone donnée traitée uniformément, qui peut être un champ, une partie d'un champ ou un groupe de champs" (Sebillotte, 1990).

Cela comprend de nombreuses opérations techniques, par exemple le choix de la séquence de culture, la couverture des cultures, le cultivar, les pratiques de transformation, la date et la densité des semences, le taux de fertilisation et le contrôle des ravageurs chimiques. Le terme « système » est utilisé ici parce que ces choix techniques sont interdépendants (Meynard et al., 2003).

Les systèmes de culture actuels (rotations courtes, utilisation de variétés productives, mais peu de maladies, semis à haute densité et fertilisation élevée) sont structurellement dépendants des pesticides. Dans le cadre de la protection et de la production intégrée, une réduction significative de leur utilisation nécessite de repenser la construction de ces systèmes, en introduisant en combinaison différentes techniques (chacune avec une efficacité partielle) permettant la création de conditions défavorables au développement des nuisibles (Aubertot et al., 2005). Plutôt que de lutter contre la population de parasites déjà développée, l'accent est mis sur la limitation de la croissance de la population elle-même (Lucas 2009). Les différentes stratégies mentionnées ci-dessus doivent être combinées. Bien que le contrôle chimique soit une solution « homogène » (pour chaque problème, nous n'avons qu'une seule solution chimique), aucune combinaison de techniques uniques ne serait adaptée à toutes les plantes (Meynard, 2008 ; Meynard et Girardin, 1991). Les combinaisons de pratiques doivent être adaptées à toutes les situations de production (Aubertot et Robin, 2013).

Lorsqu'il n'est pas possible de renoncer à l'utilisation des pesticides, il est néanmoins possible d'atténuer l'exposition des travailleurs aux pesticides. Les mesures découlent des pratiques de gestion simples à la refonte complète du système de culture.

L'exposition peut être atténuée par des simples pratiques de gestion: dans le domaine du travail, le responsable de plantation peut décider de constituer des équipes de travailleurs formés à la manipulation des pesticides. Si le gestionnaire veut opérer au niveau de l'entreprise, il peut organiser des cours de formation sur les pratiques de manipulation des pesticides et les risques pour la santé des pesticides pour tous les travailleurs de la société. Il peut également décider de sous-traiter l'application de ceux-ci à un fournisseur des services. De cette manière, il est soulagé de devoir fournir les outils pour protéger les opérateurs (par exemple l'achat d'équipements de protection individuelle et la mise en place de politiques pour les opérateurs afin de les encourager à les porter).

Dans l'état actuel des connaissances, nous devons reconnaître qu'il n'est pas toujours possible de renoncer aux pesticides. Néanmoins, il est supposé qu'il soit possible de réduire l'utilisation des pesticides en agriculture et / ou de réduire l'exposition des travailleurs sans que le système s'effondre en retrouvant les systèmes culturels. Il est donc possible de « repenser les systèmes de culture pour réduire l'exposition aux pesticides ». L'idée est de repenser le système de culture par rapport aux dommages potentiels causés à la santé des travailleurs. Pour atteindre cet objectif, il est nécessaire de pouvoir discriminer entre les différents systèmes de culture selon ce critère (dommages potentiels à la santé des travailleurs dus aux pesticides). Le besoin de discrimination entre les systèmes de culture est la raison qui justifie notre question générale de recherche:

Question générale de recherche: "Comment distinguer les différentes systèmes de culture sur la base des possibles effets des pesticides utilisés sur la santé des travailleurs agricoles?"

La question générale de recherche sous-tend la nécessité d'explorer les sous-questions suivantes:

- Comment classer les différents systèmes de culture?
- Quel est le lien entre le système de culture et les variations d'exposition?
- Quelles sont les méthodes actuelles d'évaluation de la santé des travailleurs agricoles?

Comme indiqué dans la littérature, la disponibilité d'un indicateur de risque simple mais fiable lié aux pesticides serait particulièrement pertinente (Feola et al., 2011). Le résultat attendu est de préparer la construction d'un outil d'aide à la décision permettant aux gestionnaires de plantations de discriminer les différents systèmes de culture en fonction du critère de dégradation de la santé des agriculteurs par l'exposition aux pesticides. Les principales caractéristiques de ce nouvel outil seront les suivantes: i) prendre en compte les pratiques réelles mises en œuvre par les travailleurs agricoles (y compris les «mauvaises» pratiques); ii) la simplicité de la collecte des données; iii) le traitement rapide des données.

L'outil pourra être utilisé pour évaluer les conséquences des changements dans les plans annuels et pluriannuels d'une nouvelle usine / plantation. Cette évaluation peut être réalisée soit par hectare ou par parcelle, soit pour l'ensemble de la surface cultivée au niveau de l'entreprise. Il sera possible d'évaluer la variation de la technique d'application et / ou la variation du système de culture. L'outil sera conçu à la fois pour l'évaluation des systèmes de culture existants (utilisation ex post) et pour l'évaluation des nouveaux systèmes de culture planifiés (utilisation ex ante).

Les trois sous-questions découlent de la question générale de recherche. Par conséquent, nous avons procédé à la collecte du matériel nécessaire pour répondre à ces trois questions.

A ce stade, les principales variations qui peuvent être opérées dans un système de culture ont été analysées: la variation du produit (avec une variation relative de la toxicité à laquelle les travailleurs sont exposés); la variation de la technique d'application du produit / mélange (liée à la possibilité de variation de la voie d'exposition: par exemple de l'inhalation au contact); des variations dans le système de culture (par exemple, l'introduction de "plantes de service" parmi les arbres qui réduisent le besoin d'utiliser des herbicides).

Les principales méthodologies actuellement utilisées pour évaluer l'exposition aux pesticides et les impacts sur la santé humaine sont: l'analyse du cycle de vie environnemental (ACV-E) et l'évaluation des risques (Risk Assessment - RA).

Les méthodes les plus répandues ont été examinées pour les deux méthodologies, en analysant leurs méthodes de calcul et leur capacité à répondre à notre question de recherche. Les deux méthodes se sont révélées inadaptées pour répondre à notre problèmatique. En fait, la revue de la littérature a montré comme les méthodes actuelles ne sont pas capables de gérer le problème des changements de produits, ou seront en mesure de le faire lorsque les bases de données seront plus documentées.

Fondamentalement, il y a un manque de méthodes qui évaluent les variations dans le système d'application et dans le système de culture. Aucune méthode actuelle n'est capable d'évaluer les deux types de changements d'une manière équitable. La cause est le fossé profond dans les connaissances scientifiques sur les effets de l'application de pesticides et les effets des changements dans les systèmes de culture, sur la santé humaine.

D'après les revues de la littérature, un écart se dégage en ce qui concerne l'évaluation des pratiques réelles. Lorsque des pratiques réelles sont évaluées, l'étude est liée à l'utilisation dans un contexte spécifique d'une substance unique. Il est donc impossible de généraliser les résultats. Pour ces raisons, notre contribution consiste à développer une méthode sensible aux modifications des produits, des systèmes d'application et de culture, en évaluant les pratiques réelles des opérateurs et des travailleurs exposés. Comme souligné ci-dessus, l'écart de connaissances est large et profond. Les gestionnaires doivent prendre des décisions dans un contexte où « les incertitudes du système ou la participation aux décisions (ou les deux) sont élevées » (Funtowicz et Ravetz, 1994). Nous sommes confrontés à « l'imprévisibilité, le contrôle incomplet et la pluralité des perspectives légitimes » (Funtowicz et Ravetz, 1994). Dans un tel contexte, il est nécessaire de recourir à un avis d'expert. En fait, l'idée est que les expériences des experts comprennent (et peuvent soutenir) tout le système complexe de relations intégré dans la question. Nous essayons de remplacer la science incomplète par des expériences d'experts. Étant donné que nous devions obtenir des expertises de manière efficace, il était nécessaire de réduire le champ dans lequel recueillir leurs expériences. Dans ce travail de recherche, nous avons donc choisi de nous concentrer sur la culture de la banane.

Par conséquent, nous avons fourni une image complète de la culture de la banane et du marché pour l'exportation.

La revue de la littérature a révélé qu'il est nécessaire de construire une méthode capable de discriminer les différents systèmes de production, en fonction des impacts potentiels sur la santé des opérateurs, à partir des pratiques réelles mises en œuvre dans les plantations.

Pour ce faire, notre recherche répondra aux trois questions de recherche suivantes:

- Comment est-il possible de recueillir des informations sur les pratiques réelles mises en œuvre dans la plantation?
- Comment les informations collectées peuvent-elles être représentées?
- Comment un indicateur peut-il être développé en tenant compte des pratiques réelles mises en œuvre dans la plantation?

Le positionnement épistémologique interprétativiste de l'œuvre s'est donc approfondi, justifiant le positionnement ci-dessus au détriment des approches post-positivistes et constructivistes.

Sur la base de la revue de la littérature, les méthodes actuelles (ACV-E et RA) ne permettant pas de prendre en compte les pratiques réelles, nous proposons un modèle qui prenne en compte les pratiques elles-mêmes et permet d'anticiper les impacts futurs.

Le travail est basé sur l'expérience, qui stipule que dans certaines conditions de travail particulières (telles que la chaleur et l'humidité), le risque d'exposition devient très fort, par ex. pour l'utilisation impropre de l'équipement de protection individuelle (EPI). Des experts ont été sollicités sur ce sujet par le biais d'une méthode consensuelle appelée « Delphi Expert Consensus Method » (Jorm, 2015). L'information recueillie a été représentée par des arbres de connaissances. Nous avons ensuite procédé à des tests sur nos arbres à travers l'observation d'une étude de cas réelle. Grâce aux informations recueillies par les experts et l'étude de cas, nous avons pu élaborer un indicateur qui peut être utilisé par les gestionnaires de plantations pour évaluer les systèmes de production mis en œuvre et les conséquences de tous changements (par exemple, type de produit utilisé, pratiques de plantation, organisation du travail).

Dans une première phase, le bassin d'experts a été sélectionné en choisissant des personnes ayant une expérience directe des pratiques réelles mises en œuvre dans les plantations de bananes. Le pool était composée par: agronomes, économistes et éxpologues. Tous les experts ont été interrogés séparément et anonymement. Tous les experts interrogés travaillent dans une organisation indépendante qui s'occupe d'améliorer les pratiques agricoles et environnementales. L'information recueillie à partir de l'expérience a été organisée en 9 arbres de la connaissance (Figure 3) (Huosong et al., 2003 ; Marceau, 2007 ; Yager, 2006).

A cette époque, les différents systèmes de production de bananes ont été divisés en neuf étapes de culture de la banane pour la durée d'une plantation. Ainsi, neuf arbres de connaissances (Figure 3) ont été construits correspondant aux principales phases de la culture du bananier:

1. Destruction de la vieille plantation

2. Jachère

3. Croissance dans la serre

4. Croissance extérieure

5. Fertilisation

6. Désherbage

7. Protection des plantes (contre la cercosporiose noire et les nématodes)

8. Soins du casque

9. Traitements post-récolte (dans la stationne d'emballage).

Nous avons structuré les arbres pour identifier les différentes alternatives pour les trois principales occasions d'exposition pour les opérateurs: préparation du mélange de pesticides, application de pesticides et nettoyage de l'équipement (y compris le traitement des eaux usées du mélange de pesticides), et pour les autres travailleurs produits agricoles (lorsqu'ils sont présents dans les colis traités et lorsque le délai de suspension légale après traitement n'est pas respecté).

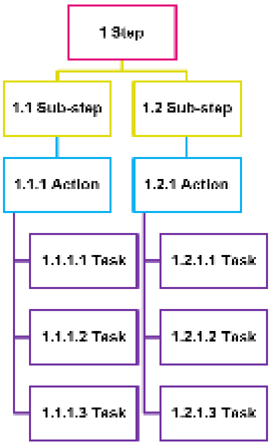

Figure 3 - Structure des arbres de connaissances

Nous avons organisé les graphiques dans l'ordre chronologique: nous avons d'abord identifié les différentes étapes qui composent un système de production de bananes. Pour chacune d'entre elles, les sous-étapes à mettre en œuvre ont été mises en évidence. Nous avons donc identifié des actions opérationnelles alternatives pour effectuer chaque sous-étape, parmi lesquelles le choix peut être fait. Enfin, chaque action implique que trois activités (tâches) sont réalisées (où il y a, potentiellement, une exposition aux pesticides): la préparation, l'application et le nettoyage des instruments.

Les pratiques effectives concernant tous ces facteurs sont prises en compte par les experts, lorsqu'ils considèrent que telle ou telle tâche est réalisée avec un tel niveau d'exposition.

En outre, les entretiens d'experts mettent en évidence les critères pertinents qui nous permettent de concevoir les différentes branches de l'arbre des connaissances. Les critères pertinents qui créent des bifurcations entre les différentes branches sont: les méthodes d'application et les «politiques EPI». En effet, dans les organigrammes, la présence (ou non) des «politiques EPI» était incluse. Nous appelons «politiques EPI» les initiatives mises en place par le responsable de la plantation pour inciter les opérateurs à porter les Equipements Individuels de Protections (EPI). Il s'agit généralement de formations sur les risques liés aux pesticides et sur l'utilisation des EPI, ou des primes (normalement salariales).

Ces arbres de la connaissance nous ont permis de dessiner des arbres de décision.

Alors que les arbres de connaissances contiennent des informations sur les opérations qui peuvent se dérouler ensemble dans la même étape (par exemple, traitement avec des fongicides et traitement des nématodes pendant la phase «protection des plantes»), les arbres de décision ne contiennent que des branches exclusives les uns des autres (par exemple, un traitement avec des fongicides peut être conduit avec un avion / hélicoptère ou par atomiseur à dos).

L'objectif poursuivi avec l'élaboration des arbres de décision est d'organiser l'information nécessaire au calcul de l'indicateur, mais surtout en vue d'une informatisation éventuelle des connaissances recueillies par les experts.

Nous posons l'hypothèse que nous pouvons « estimer » le coût humain du pesticide pour l'opérateur moyen en ajoutant les « coûts humains » des pesticides des tâches dans lesquelles il est investi.

Le « coût humain » des pesticides d'une tâche pour l'opérateur moyen est proportionnel au nombre d'opérateurs réalisant l'activité, au nombre d'événements, au degré d'exposition de l'opérateur moyen et à la toxicité. Les données nécessaires pour calculer le coût humain d'une tâche sont:

- le nombre d'opérateurs effectuant la tâche;
- le nombre de répétitions de l'activité, qui dépend du nombre de répétitions du traitement en question. Nous croyons que chaque action indique les trois tâches «préparation, application, nettoyage», mais celles-ci peuvent ne pas concerner le même nombre d'opérateurs et seront calculées séparément;
- le degré d'exposition de l'opérateur moyen indiqué par les experts, pour cette partie du système de production et pour cette modalité de traitement, indiqué dans l'arbre de décision;
- la toxicité du produit. Il est recommandé d'utiliser l'inverse (1 / AOEL) du niveau d'exposition acceptable de l'opérateur (AOEL) (exprimé en mg du produit par kg de poids corporel par jour) du produit concerné.

L'indicateur représentant la mise en œuvre d'une action composée des trois activités connexes (préparation, application, nettoyage) peut être exprimé comme suit:

$$Human\ cost_{operators} for\ one\ action = \left(\sum_{j=1}^{3} k_j T_j w_j \frac{1}{AOEL_j} \right)$$

où:

- j représente l'une des trois tâches suivantes: préparation, application ou nettoyage.

- k_j représente le nombre d'opérateurs impliqués dans cette activité.
- T_j indique le nombre de fois que l'activité est répétée, dans les mêmes conditions, sur le périmètre du calcul de l'espace-temps.
- w_j reflète le niveau d'exposition de l'opérateur et a été identifié dans les arbres de connaissances en fonction d'une tâche spécifique à un point spécifique du système de production.
- $AOEL_j$ identifie le AOEL du produit utilisé dans la tâche j.

Mise en œuvre de l'étude de cas

La santé des travailleurs peut être influencée de différentes manières et pour des raisons liées à l'exposition aux produits chimiques sur le lieu de travail, mais elle pourrait aussi être indépendante de celle-ci. En particulier, nous n'avons pas créé nos arbres et l'indicateur en tenant compte de l'exposition générale aux produits chimiques (par exemple, l'exposition aux produits de nettoyage, tels que l'eau de Javel et les détergents). De la même manière, nous ne tenons pas compte des pathologies qui ne dérivent pas directement de l'exposition aux pesticides sur le lieu de travail (par exemple, les maladies musculosquelettiques, les troubles génétiques préexistants). Nous n'avons même pas considéré l'impact dû à l'exposition dans un contexte domestique (par exemple, pendant le jardinage). Par conséquent, notre étude ne traite que des impacts causés par l'exposition professionnelle des opérateurs aux pesticides, dans le cas des plantations de bananes destinées à l'exportation uniquement.

Le test visait à contrôler les difficultés que le praticien peut rencontrer en essayant d'évaluer son système de production en appliquant la méthode décrite ci-dessus. Dans ce travail de recherche, nous voulons définir une méthode simple à mettre en œuvre et qui peut être utilisée avec succès par les managers des plantations, avec une simple collecte de données et une mise en œuvre rapide.

En détail, le test de faisabilité visait à:

- Identifier un système de production spécifique mis en œuvre dans un cas réel parmi les systèmes de production décrits par les arbres de connaissances. Le test tente de répondre à la question suivante : pouvons-nous identifier rapidement et facilement un système de production réel donné à partir de la combinaison d'arbres de connaissances? Cette identification nous permet de connaître le w_j de chacune des activités mises en œuvre.
- Vérifier si les autres données nécessaires au calcul de l'indicateur sont simples ou ne doivent pas être collectées sur la plantation.

- Vérifier si nous pouvons facilement trouver des alternatives pour améliorer le système de production ou pour aider à concevoir de nouveaux systèmes de production.

Après avoir obtenu et interprété les résultats du calcul de l'indicateur « coût humain », nous avons proposé des améliorations à la méthode.

Le lieu de mise en œuvre de l'étude de cas a été la République Dominicaine. Nous avons étudié le contexte spécifique dans lequel nous nous trouvions, en analysant à l'avance le contexte historique de la culture de la banane dans le pays, le rôle primaire qu'elle joue dans l'économie nationale, la structure des plantations, les problèmes sociaux à résoudre connectés (par exemple, le flux d'immigrants d'Haïti destinés à travailler sur la plantation).

Quatre entrevues semi-structurées ont été menées avec quatre managers de plantations.

Quatre personnes étaient disponibles pour être interrogées (I1, I2, I3 et I4), où I1 et I2 se réfèrent à de grandes plantations et I3, 14 se réfèrent à de petites plantations.

Les quatre personnes interrogées étaient: un propriétaire de plantation (I1), un président d'un sociétéqui possède une plantation (I2), un contremaître de plantation (I3) et un superviseur de plantation (I4). I3 a été soutenu par le superviseur technique de l'association des producteurs pour répondre à nos questions.

Les interviews ont été réalisées avec un traducteur de l'anglais / français vers l'espagnol. Chaque entrevue a duré en moyenne 2 heures. Les lieux des entretiens étaient les suivants: la maison d'un propriétaire de plantation (I1); le siège de la société propriétaire de la plantation, située à côté de la plantation elle-même (I2); l'usine d'emballage (I3); la zone à l'entrée de la plantation (I4).

Les interviews ont été divisées en cinq parties:

1. Introduction, composé de neuf questions. Dans cette première partie, nous avons recueilli des informations générales sur la plantation et la personne interviewée, comme son rôle dans la plantation (il était le propriétaire de la plantation ou juste un employé?). L'étendue, l'âge de la plantation, le nombre de travailleurs employés dans la plantation et le fait que le producteur faisait partie d'un groupe de producteurs.
2. Informations détaillées sur la plantation. Cette section comportait seize questions. Dans cette section, nous avons étudié plus en détail qui est le propriétaire du terrain, quels produits ont été cultivés sur ces terres (seulement la banane ou non? Cela a été très important pour notre problème en raison de la quantité et les types de produits chimiques

utilisés) et si les bananes cultivées sur cette plantation étaient destinées ou non à l'exportation. Dans cette partie, nous avons également recueilli des informations sur la mise en œuvre des pratiques culturelles, en vérifiant qu'elles ont été comprises et suivies dans nos arbres de connaissance. Par exemple, on a examiné si un fournisseur de services était utilisé pour faire des applications de pesticides, et à quelles étapes, et la présence d'une «équipe» pour l'application de produits chimiques directement sélectionnés parmi les travailleurs des plantations (opérateurs) et de combien d'éléments étaient composés cette équipe. Si présent (à la fois le fournisseur de services et «l'équipe»), dans quelle phase ils ont été utilisés et combien de fois par an. En particulier, pour «l'équipe», il y avait une question sur le type d'EPI utilisé (bottes, combinaisons, lunettes, etc.).

Il y avait des questions sur les pratiques générales appliquées en plantation, par ex. s'il y avait un endroit spécifique où les produits phytopharmaceutiques étaient stockés, s'il y avait un endroit spécifique où les EPI non encore utilisés étaient stockés, où les opérateurs pouvaient stocker leurs vêtements lorsqu'ils portaient des EPI, s'il y avait un processus de gestion des EPI utilisés (par exemple, sont-ils stockés quelque part? Sont-ils éliminés quelque part? Sont-ils réutilisés?).

À la fin de cette section, nous avons recueilli des informations sur:

- "politiques PPE": si des formations ont été organisées par rapport à la nocivité des pesticides et / ou des maladies liées au contact avec elles ou si des primes / paiements salariales ont été versés aux opérateurs pour inciter le port des EPI
- gestes techniques pour la protection des végétaux (défoliation, etc.) qui peuvent éviter ou réduire l'utilisation de produits chimiques
- le rôle de l'association de producteurs (si le producteur fait partie d'une association) dans des activités liées aux pesticides (par exemple formation, achats collectifs, etc.).

3. Dans la troisième partie, nous avons étudié si les phases de plantation que nous avons identifiées, sont mises en œuvre dans un cycle de culture. Pour les principales étapes, nous avons recueilli des informations sur les produits utilisés, la fréquence de traitement et les activités mises en œuvre.

   À la fin de cette section, nous avons examiné les méthodes de préparation du mélange et les méthodes utilisées pour appliquer les différents pesticides.

4. La quatrième section contient des informations sur l'activité de nettoyage des instruments. L'information sur cette tâche n'a pas été recueillie par les experts parce qu'ils ont dit qu'ils n'en ont jamais vu ça pendant leur carrière. Nous avons examiné la présence ou l'absence d'une phase de nettoyage de l'instrument, à quelle fréquence il est effectué et par qui, la place et, enfin, la présence de processus de gestion des eaux usées.
5. La dernière partie du guide d'entretien contenait des questions à l'intention des travailleurs des plantations, sur leur niveau d'alphabétisation, l'utilisation des EPI, les raisons qui les conduisaient à ne pas les utiliser, les heures de travail, suspension après traitement.

Les entretiens ont été entièrement retranscrits et analysés en fonction des objectifs du test.

Selon le nombre d'entrevues signalées dans les entrevues avec les gestionnaires de plantation, de petits changements ont été apportés aux arbres de connaissances et de décision.

Implications du travail

Dans le dernier chapitre de l'élaboration, le présent travail de recherche a été inséré dans le cadre des méthodologies déjà répandues pour l'évaluation des impacts sociaux et socio-économiques d'une production. En particulier, les questions liées à l'Analyse du cycle de vie sociale (ACV-S) ont été étudiées.

Tel que rapporté par Macombe (2017), les principales utilisations de l'ACV-S sont:

- Fournir des connaissances sur certaines des principales conséquences du changement (quels sont les principaux impacts en termes de santé publique et de santé des travailleurs concernés ?);
- Aider la coordination des acteurs (par exemple, en tant que base de discussion sur la configuration du projet);
- Influencer les décisions sur les projets futurs. Les études issues de l'ACV-S mettent en évidence les principaux problèmes sociaux et les demandes de changements dans le présent projet qui peuvent être marginaux du point de vue technique, mais très importants du point de vue social;
- Aider à développer le côté social des projets. L'ACV-S remplit le volet social des projets, rapportant différents aspects sociaux (attendus et inattendus) et nécessitant des changements si nécessaire;

- Générer des innovations guidées par des considérations sociales (par exemple en atténuant les impacts sur la santé des pesticides, comme dans ce travail spécifique).

Entre 2005 et 2008, l'Organisation mondiale de la santé a décidé de créer une «Commission des déterminants sociaux de la santé» (CSDH), chargée d'expliquer la relation entre la santé de la population / les familles et de nombreux autres facteurs (droits fonciers, travail décent, corruption, etc.). L'objectif était de reconnaître officiellement les liens entre les conditions sociales et sanitaires pertinentes, afin de conseiller les décideurs politiques pour des politiques de santé (intersectorielles) saines.

Dans le rapport de la CSDH (OMS, 2009), les auteurs ont divisé les déterminants sociaux en deux échelles:

- l'échelle «macro» d'un État ou d'une grande région dans les pays en développement,
- l'échelle «méso» d'un groupe de familles rurales, dans les régions rurales des pays en développement.

Le présent travail vise à encourager le travail décent en identifiant les choix possibles les moins nocifs pour la santé et la garantie d'un environnement et d'une sécurité sains. Le résultat de l'ensemble de ce travail de thèse est formalisé dans une voie méso-échelle, appelée «*pathway* de Wesseling».

Cette voie peut être détaillée en représentant la chaîne de cause à effet entre les opérations de culture et la toxicité aiguë. Cela peut être représenté divisé en trois parties:

1. Planification. À ce stade, le décideur (par exemple, directeur d'usine, consultant) décide quelles étapes de production doivent être entreprises pour obtenir le produit agricole désiré (par exemple, un produit avec: une jauge requise, des caractéristiques physiques particulières, sans signes de présence d'animaux nuisibles). En fonction du produit désiré, il a également défini les sous-phases et les actions et les modalités pour les exécuter en termes de:
    a. Besoin ou non d'application de pesticides.
    b. Type de produit (chimique ou non) à appliquer.
    c. Nombre de répétitions de l'application (ce nombre peut être modifié en raison d'événements imprévus, tels que des conditions météorologiques inhabituelles).
    d. Détermination ou non des conditions de préparation en ce qui concerne: les instruments à utiliser pour la préparation du mélange (par exemple, les cuves de

mélange), le lieu où la préparation doit avoir lieu, personne/s responsable/s de l'exécution de cette tâche.

   e. Détermination des conditions d'application, en termes de: outils particuliers à utiliser dans l'application de pesticides (par exemple, avion, quad, pulvérisateur à dos), personne/s responsable/s de l'exécution de cette tâche. Dans cette partie, le décideur peut également planifier l'organisation du travail dans la plantation (par exemple, création de groupes d'application de travailleurs entièrement ou principalement dédiés à l'application de pesticides).
   f. Détermination des conditions de nettoyage de l'instrument, en termes de: outils à utiliser dans la tâche de nettoyage (par exemple, outils spéciaux), endroit où le nettoyage doit avoir lieu, personne/s responsable/s de l'exécution de cette tâche.
2. Mise en œuvre. Dans cette deuxième phase, il y a le développement concret des différentes tâches. C'est à ce stade que des conditions défavorables (par exemple : la chaleur, l'humidité, la pente) peuvent affecter ce qui a été prescrit dans la première phase. Dans la phase de mise en œuvre, nous observons également l'utilisation ou non des EPI et, plus généralement, des mauvaises pratiques.
3. Conséquences. Dans cette phase, nous observons l'exposition associée et les conséquences en termes de toxicité aiguë. Nous soulignons que c'est la seule phase dans laquelle le décideur n'a aucun pouvoir d'intervention.

En ce qui concerne les perspectives du présent travail, elles peuvent concerner le développement de l'indicateur proposé afin d'évaluer la multi-exposition aux produits phytopharmaceutiques, à la fois en termes d'exposition répétée au même produit et d'exposition à plusieurs produits au même temps. Deuxièmement, l'indicateur du «coût humain» peut également être développé pour les travailleurs agricoles génériques (ceux qui ne sont pas responsables de l'application des produits phytopharmaceutiques, mais qui sont, dans tous les cas, exposés en raison de l'application faite par autres) et pour les riverains des sites de production agricole. L'indicateur peut également être développé pour d'autres phases du cycle de vie de la protection des cultures (par exemple, la phase de production des produits chimiques) afin de fournir une perspective large dans la phase de prise de décision, en particulier pour toute décision au niveau des politiques publiques.

Cet indicateur a été développé en prenant en considération uniquement le cas de la production de bananes pour l'exportation. À l'avenir, il est envisagé de travailler sur une adaptation à d'autres cultures, en tenant compte de leurs spécificités.

En outre, les auteurs conseillent le développement d'études de cas pour comparer la production agricole conventionnelle et les productions agricoles qui ont obtenu un label de nature social. De l'observation du contexte et de quelques témoignages également documentés dans la littérature, l'obtention d'un résultat favorable pour la production labellisée quant à l'amélioration des conditions de travail n'est pas considérée comme acquise.

Enfin, les auteurs encouragent l'utilisation d'approches participatives dans la conception de systèmes de culture innovants et dans le développement d'études de cas en mettant en œuvre la méthodologie de l'ACV-S.

Introduction

Pesticides are agrochemicals used in agricultural lands, public health programs, and urban green areas in order to protect plants and humans from various diseases (Nicolopoulou-Stamati et al., 2016).

The issue of the health effects of pesticides raises public concern that has been on the political agenda for several years. Several parliamentary reports have recently contributed to the debate (Inserm (dir.), 2013).

Pesticides & scandals

During the 70's, first testimonies about pesticide use and health problems began to emerge and this issue began to interest the public opinion. Jas (2010) refers that, in 1972, during a TV presentation of the *"1er Congrès international de la défense de la Nature"*, one of the participants declared:

"... I once spit blood after chemical treatments with which I poisoned myself ... everyone knows that chemicals are carcinogens"

Since 2002, the matter of the effects of pesticides on the health of farmers seems to acquire a certain visibility in the public space under the effect of two initiatives. On the one hand, a series of lawsuits have been initiated by farmers to ensure that occupational exposure to one or more pesticides was recognized as causing serious harm to their health. On the other hand, the results of epidemiological surveys showed that this type of exposure would lead to increased risks for certain pathologies. The media interest of these legal actions and investigations, which still only concern certain professional groups and certain pathologies, is recent. This could suggest that the effects of pesticides on the health of agricultural workers could cause new and diverse problems.

Pesticides use was under the spotlight more and more often in recent times. Scandals interested both agricultural and farming products (e.g., dairy products, eggs (Boffey and Connoly, 2017), meat), both conventional and organic agriculture (Muller and Garbay, 2017) and farming.

The causal relation between pesticide exposure and human health was debated also by NGOs. In 2015, for example, Greenpeace published a report entitled "Pesticides and our health – a growing concern" (Greenpeace, 2015). In this report, the authors deepen for the great audience what is the role of pesticides in our agriculture, possible exposure occasions (e.g., food consumption, occupational and residential exposure), and who are particularly exposed and vulnerable populations. Moreover, the report provides an overview of health impacts linked to pesticide exposure (e.g., cancer and damages to the nervous system). The authors identified a possible solution in the ecological farming (e.g., organic agriculture).

Accordingly, another line of discussion is represented by the actual safeness of organic products, if compared with the conventional ones. Organic food is increasing year by year. With double-digit growth rates (+ 14% in 2016), it generated € 1 billion in revenue in France in 2000 and more than € 5 billion in 2015. On this topic, Tymen (2016) reported a comparison inquiry on organic vs. conventional salmon. On ten freshly tested cobbles of Norwegian, Irish or Scottish origin, only the four organic salmon pavers are contaminated.

In agricultural products field, in the minds of many consumers, "bio" has become synonymous with "untreated". In a Harris Interactive survey conducted in March 2016, one in two people said they were convinced that organic farming did not use any treatment. That's far from being the reality. There are hundreds of certified organic specialties. The regulation also sets maximum residue limits (MRLs) specific to organic plant health products, to be found in organic food. The producers respect them. In a fraud administration survey published in November 2013, one organic product out of 65 was not compliant, which corresponds to the deficiencies generally found in conventional agriculture (1% to 3% of infringements). One of the driving forces of the organic's rise is the proven or suspected danger of synthetic plant protection products used in conventional agriculture. However, at the same time, published studies about plant protection products admitted in organic cultivation, which represent a risk for environment and/or human health, are coming out. Two examples are: the Spinosad, organic insecticide, considered very toxic to pollinators (bees or bumblebees), and the Rotenone (banned in April 2011 at the European level, after years of employment in organic agriculture). Since 2008, US studies have shown that this molecule extracted from a tropical plant increases the risk of Parkinson's disease in the user[2].

If we consider the specific case of banana production, a scandal raised in 2017 in the occasion of the *"54e Salon de l'agriculture"* in Paris[3].

[2] More information at: https://erwanseznec.wordpress.com/2016/09/29/toxiques-naturellement/ .

[3] More information, for example, at: https://www.ouest-france.fr/europe/ue/la-banane-bio-d-importation-pas-si-bio-4828843 ; http://www.francetvinfo.fr/replay-radio/question-de-choix/question-de-choix-les-bananes-bio-sont-elles-vraiment-bio_2082613.html ; http://www.lemonde.fr/economie/article/2017/03/06/la-banane-

First of all, almost all "organic" bananas consumed in the European Union come from countries such as Ecuador, Dominican Republic and Peru.

"In Europe, only banana producers in the Canary Islands come here [are organic] because they are located in a dry tropical climate. But because of imports, they cannot value their production"

Philippe Ruelle, General Manager of UGPBAN.

French banana producers criticized organic bananas from Central and South America, especially from Dominican Republic, for being entitled to the organic logo, without having to comply with European specifications.

"These countries use 25 plant protection products, including aerial spraying, 14 of which are not allowed in Europe. Certifying bodies, approved by Europe, only control compliance with local organic regulations and allow them to sell under the European organic label."

Declared Éric de Lucy, the president of UGPBAN, the Union of groups of banana producers from Guadeloupe and Martinique.

"These bananas are stamped organic. But the consumer is abused. Producers allow aerial spraying and can spend up to 25 times with an oil, the Banole, that we can only spend six times in France, in conventional. On the other hand, they can use 14 prohibited substances at home, not to mention the fact that socially, we are much better. A Haitian in the Dominican Republic is paid $ 5 a day"

Explained Sébastien Zanoletti, in charge of sustainable agriculture at the Union of Banana Growers of Guadeloupe and Martinique (UGPBAN). So, we would sell "fake" organic bananas.

Denouncing unfair competition, the UGPBAN (650 producers), the largest private employer in the Caribbean (10,000 jobs), prefers to highlight the quality of French West Indies production (280,000 tons annually), "better than the import bio". From 2006 to 2016, farms reduced pesticide use by 61% in the 8,500 ha of cultivated land in Martinique and Guadeloupe, without however reaching organic farming.

Sébastien Zanoletti also underlined these efforts made by producers in Martinique and Guadeloupe, nevertheless, without achieving organic farming:

antillaise-veut-contrer-sa-rivale-bio_5089822_3234.html ; https://reporterre.net/La-face-cachee-de-la-guerre-de-la-banane-bio .

"We have reduced the use of pesticides by 60%."

Zanoletti's statements reveal other issues that are beginning to emerge from newspaper headlines: exploitation of workers and poor respect for human rights.

For example, in recent years, the Dominican Republic has specialized in producing organic and fair-trade bananas: 70 percent of the bananas produced are organic, and about 40 percent are included in “fair trade circuits”. One third of the banana from fair trade circuit consumed in Italy comes from Dominican Republic. This market niche has allowed the small Caribbean state to play a role next to the World's largest exporters: Ecuador, Colombia, Costa Rica and various other "banana republics" from Central America.

The bananas produced in Dominican Republic enter the fair-trade circuit, which means that every fruit basket receives an additional 1-dollar bonus to be used in social or community development projects or in initiatives for workers. Plantations’ workers live near the plantations in the so-called “batey”. Created in the ‘30s for sugarcane workers from Haiti, today the “batey” are ghetto neighbourhoods of Haitian immigrants, mostly distant from the inhabited centres. There is flowing water, but the electricity arrives in hiccups: in the “bateys” is suspended between 1pm and 4pm, and between 8pm and 8am of the day after. Many residents have no documents: even if they are born in the Dominican Republic, they do not have the right to citizenship. Or they lost it: in 2013, a very controversial ruling by the Constitutional Court deprived the descendants of Haitian immigrants born in Dominican territory since 1929, creating an “army” of stateless persons day after day. Moreover, Dominicans often have higher pay, because they have more responsibilities. Haitians have to settle for the minimum wage, which is 267 pesos per day (the equivalent of five euros). Some earn less, even 250 pesos. "We cannot do it, but we have no alternative," they all say (Liberti, 2017).

As a result, the current actions to incentive fair trade politics have to get deeper into the social issues that affect the productive realities, before setting out regulatory frameworks.

Another thread of debate in public opinion regards the authorization of Plant Protective Products (PPPs) in Europe. At the October 26, 2017 Conference of Presidents of the European Parliament, the Greens/EFA group(The Greens/EFA group, 2017a, 2017b) announced that they will start collecting signatures for the establishment of an inquiry committee on glyphosate. The purpose of the committee would be to investigate the handling of the decision-making process for the proposed renewal of glyphosate's licence.

Greens/EFA president Ska Keller commented:

"We have serious concerns about whether the rules have been respected during the decision-making process for glyphosate. The European Commission, the European Food Safety Authority and the European Chemicals Agency need to ask themselves critical questions and explain why scientific studies demonstrating that glyphosate is dangerous have been ignored."

"The committee of inquiry must clarify how to improve decision-making and evaluation processes so that they are made transparent and objective. This is urgently needed to ensure that decisions in the EU are determined by public and not private interests."

From this brief overview, emerges that the field of pesticides is a sensitive issue. The problem becomes thornier when it comes to tropical Countries.

Pesticides in tropical Countries

In Developing Countries (often situated in tropical climate zones) pesticide poisoning is recognized as a major health problem (e.g., Jeyaratnam, 1985a, 1985b; Van Der Hoek et al., 1998). On the other hand, pesticides, especially insecticides and fungicides, are more heavily applied for tropical cash crops — such as banana, coffee, cotton and vegetables — than for crops in temperate regions. For example, the application of pesticides in banana plantations in Costa Rica attained 45 kg (active ingredient) per hectare, whereas the comparable average application of pesticides in Japan for crops is 10.8 kg (Carvalho et al., 1998).

In addition, occupational exposures predominated among the cases and could be identified with: (1) careless handling during preparation and application; (2) lack of personal protective equipment or failure to use it due to heat-related discomfort; (3) laxity of safekeeping of the chemicals; (4) careless disposal of empty pesticide containers; (5) consumption of food and beverages while working; (6) lack of personal hygiene; (7) deficiencies in safety training; and (8) weaknesses in occupational health legislation and regulations (Ecobichon, 2001).

Confirming the importance of the impacts of pesticides on the environment (in the broad sense), experts have estimated that, in tropical regions, only a minor fraction of applied pesticide — less than 0.1% — reaches the target pest species; excess pesticide moves throughout the environment potentially contaminating soil, water, and biota (Carvalho et al., 1998).

Estimations of impacts of pesticides in tropical countries were developed especially in the Risk Assessment[4] field. This methodology, with the Environmental Life Cycle assessment one, is one of the most used to evaluate pesticide impacts (a deep analysis of both is provided in Chapter 2).

Regulation in Northern and Southern Countries

About the "pesticide concern" in Northern Countries bloomed a great number of regulations, handbooks, etc.

Council Directive 91/414/EEC requires that the residues of plant protection products (PPPs) applied in accordance with good plant protection practice must not have "any harmful effects on human or animal health" (EFSA, 2010). But methods for assessing the harmful effects are not consensual. Currently, there is no harmonized approach to pesticide exposure assessment for operators, workers, bystanders and residents. In fact, no well-standardized methods are available to assess the exposures of bystanders and residents, and different Member States follow different approaches (EFSA, 2010).

Moreover, for some exposure scenarios, especially for workers, bystanders and residents, but in some cases also for operators, the empirical data from which to estimate exposures are relatively limited.

Environmental Product Declarations (e.g. Environdec 2015) and other types of labels (mobilizing Environmental Life Cycle Assessment), have been extensively used in industry as a means of communicating transparent and comparable information about the life-cycle environmental impacts of food products. As already mentioned, such labelling schemes have not always been successful in communicating environmental sustainability information in an immediate and transparent fashion. The development of an EU LCA based environmental footprint (PEF) is intended as a means to address these issues and should set an example for the future development of similar labelling schemes in other regions of the World (Notarnicola et al., 2017). But the request was not to harmonize the existing standards but to develop an approach that could be used in existing or new EU policies (Galatola and Pant, 2014).

[4] Usually these studies analyse impacts of a specific product, on a specific population (e.g., operators, residents, workers' wives, etc.) in a specific geographical context. It is also possible to find studies referring to a broader geographical area, as an entire Country.

Otherwise, it is essential that the initiatives such as that of the EU concerning a harmonized and unique LCA based product footprint become active in order to effectively and concisely communicate environmental information about food products to consumers (Notarnicola et al., 2017). According to the documents released, the PEF methodology is built on existing life cycle assessment-based methods and aim at harmonizing them. Rather than proposing a harmonized compromise of existing standards, it presents an entirely new one which is even in conflict with the existing ISO 14044 (2006). As such, PEF does not contribute to harmonization, but rather to confusion, proliferation, and mistrust (Finkbeiner, 2014).

On the contrary, and paradoxically, in Southern Countries, where the risk of health impacts due to pesticides is higher, there are less regulations and guidelines about pesticides manipulation.

The Food and Agriculture Organization of the United Nations (1990) published the "Guidelines for Personal Protection When Working with Pesticides in Tropical Climates". These Guidelines are aimed principally at government registration officials and agricultural officers and consultants and others in the field who may be asked by farmers for information about the safe use of pesticides in tropical conditions. After a brief paragraph to explicate what are pesticides' hazards and where/in which way a population could be exposed to pesticide, the guidelines illustrate the fundamental principles of personal protection (e.g., reading and understanding labels, avoiding contamination, personal hygiene). After that, the report highlighted some personal protection practice when working in hot climates, to take care and maintenance of work clothing and protective equipment as well as general advice when working in these conditions. Indeed, the wearing of additional protective clothing and other equipment may cause severe discomfort, and even physical distress due to heat stress, if they are made of inappropriate materials. Alternatively, because of the discomfort, operators may dispense with protective apparel and become subject to greater exposure and possible contamination.

The guidelines suggested, where possible, to use a pesticide formulation which does not require the wearing of additional items of protective clothing. In addition, the guidelines advise to apply the pesticide in the cooler hours of the day when it is more comfortable to wear protective equipment.

Then, the role of work clothing and additional protective equipment as supplementary protection from pesticide exposure is analysed. The guidelines provide also a small memorandum about the protection clothing maintenance in tropical context.

In other sections, the role and the maintenance of the different specific protections (e.g., gloves, glasses, facial protection, boots, gloves, etc.) are detailed.

Conclusion

The analysis of the context in which the different actors of the value chain of an agricultural product operate, showed that there is really a problem of society, regarding how to manage the "pesticide concern". This is the subject of numerous reports, scientific articles, blogs, newspapers' and magazines' articles. All this "movement" around the pesticides concern does not help in simplifying the situation. On the contrary it is complicated to set an approach of analysis. Even less it was agreed on what could represent a solution for the growing (health) problems generated by pesticides' immoderate use.

Thesis structure

This thesis is organized in four parts. In the Part 1 we will detail the state of the art about pesticide issues, viable solutions and evaluation methodologies. In Part 2 we will present the research design and set the research method. Part 3 will display results and the feasibility test. Finally, Part 4 will concern limits, recommendations and implications of this thesis work.

In the Annexes we will detail how to redesign banana cropping systems in tropical areas (Annex 1), the knowledge and decision trees devised (Annex 7 and Annex 8), the questionnaire prepared to be given to plantation managers in the English (Annex 2) and Spanish version (Annex 3), the interviews' transcription (Annex 4), the significant images collected during the case study observation (Annex 5). In Annex 6 we detail the publications concerning this dissertation. In Annex 9 we will propose a formalisation for knowledge trees for generic farmworkers (not applying pesticides).

Chapter 1: Pesticides issues and viable solutions

Focusing on analyzing impact on human health due to pesticide exposure, we can point out as numerous disciplines have focused on this theme. We can group these disciplines as follows:

- Chemistry, in particular toxicology, focuses on the toxic effects of pesticides and their relevance for human health (e.g., Hernández et al., 2013) and/or on the identification of viable solutions to reduce poisoning (e.g., Konradsen et al., 2003).

Also, medical disciplines debated about correlation between pesticide exposure and human health, in particular:

- Epidemiology focus on the incidence of the various disease on the exposed populations, such as cancer in banana plantation workers in Costa Rica (Wesseling et al., 1996) or diabetes on licensed pesticide applicators (Montgomery et al., 2008). Epidemiological studies are characterized by robust boundaries in term of time, place and population under scrutiny. For example, Montgomery et al. (2008) consider diabetes incidence, from 1999 to 2003 (specific temporal boundary), on non-Hispanic White males licensed pesticide applicators (specific population) exposed between 1993 and 1997 (specific temporal boundary), in Iowa and North Carolina (specific geographical boundary).
- Pediatrics analyze residential exposure during childhood and disease incidence, e.g., the work by Chen et al. (2015) aimed to examine associations between residential childhood pesticide exposures and childhood cancers, or the long-term effects of pesticide exposure on very young people (Mascarelli, 2013).
- Gynecology and andrology debate about common potential pesticide exposures, focusing on the associated health risks to fetal development (e.g., Gilden et al., 2010) and on male fertility (e.g., Sharma and Goyal, 2014; Sheiner et al., 2003).
- Public health sciences study both the relation between exposure and onset of diseases like cancer and neurotoxicity (e.g., Alavanja et al., 2004), neurobehavioral effects (Baldi et al., 2011), depression (e.g., Beseler et al., 2008; Kim et al., 2014) and both the source of exposure and public health implications of a particular substance (e.g., Jaga and Dharmani, 2003). They analyze also phenomena like para occupational or carry-home exposures (Hoppin et al., 2006). In particular occupational health analyzes both the concerns about environmental and human consequences of widespread pesticide use (e.g., Blair et al., 2015; Jeyaratnam, 1985), and consequences for targeted populations, as women in Developing Countries (London et al., 2002), or irrigation workers in Ghana

(Clarke et al., 1997). This discipline is also interested in studying methodological issues linked to a better assessment (e.g., Arcury et al., 2006; Damalas and Eleftherohorinos, 2011).

Agricultural and environmental sciences are involved in pesticides exposure study.

- Agricultural sciences are interested in assessing practices and gestures able to reduce exposure to pesticides (e.g., Henry and Feola, 2013; Mghirbi et al., 2015), or to evaluate alternative scenarios to pesticide usage (e.g., Savary et al., 2000; Webster et al., 1999).
- Environmental sciences mainly focus on emissions of pesticides (e.g., Dijkman et al., 2012) and on pollution due to pesticide use (e.g., Geissen et al., 2010).

In this research work, we will refer to the occupational health's approach. We will use, where possible, the glossary of this discipline. Where will be given definitions referring to other disciplines, this will be explicitly stated.

In this chapter, we will deal with definitions (§ 1.1), with benefits and hazards of pesticides (§ 2.2) with viable solutions (§ 2.3), and finally with the possibility of redesigning cropping systems to reduce exposure (§ 2.4).

1.1.Definitions of concepts useful in pesticides issues

After the review of the scientific disciplines which have handled the issue of pesticide use and its effects, we define some concepts in order to properly set the scientific frame of our study. We provide the definitions of pesticide (§ 2.1.1), and the definition of the terms exposure, dose, concentration (§ 2.1.2) and toxicity (§ 2.1.3).

As highlighted in the introduction section, we have seen that pesticide usages have become a social problem, where engineering and science have been called.

1.1.1. Definitions of Pesticide

The word "pesticide", a generic term derived from the Latin terms "*caedere*" (killing) and "*pestis*" (scourge), which was incorporated into the English language in the 1940s and then into the French language in the late 1950s, is used in both current and scientific language. Pesticides have the main characteristic of controlling pests (animals, plants, fungi), but they can also regulate the growth of plants, have defoliating or desiccating properties, or they can improve the storage or transport of crop products (Inserm (dir.), 2013).

There are several definitions of a *pesticide*. The International Code of Conduct on the Distribution and Use of Pesticides[5] (FAO, 2003) defines a pesticide as:

"[...] any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. The term includes substances intended for use as a plant growth regulator, defoliant, desiccant or agent for thinning fruit or preventing the premature fall of fruit, and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport."

It is evident that a pesticide, thus defined, is used for the variety of benefits it provides to mankind. In doing so, there are certain undesirable and unwanted effects of pesticide usage which cannot be ignored (Jeyaratnam, 1990).

The Council on Scientific Affairs of the American Medical Association (1997) stated that:

"Pesticides include a diverse group of chemicals and biological agents that are intentionally applied to the environment for the selective control of plants, animals, or microorganisms. […] *In agriculture, pesticides are used to control a variety of insects, weeds, and microorganisms that can destroy growing or harvested crops."*

Regarding their use, the products commonly referred to as 'pesticides' are sorted into four separate European regulations, according to their use: plant protection products (PPPs), biocides, veterinary medicinal products and medicinal products for human use. These regulations have been put in place in order to establish a harmonized legal framework within the European Union (Inserm (dir.), 2013). In this research work, when we will talk about "pesticide" we will refer to plant protection products only.

[5] The objectives of the Code are to establish voluntary rules of conduct for all public and private bodies involved in distribution and use of pesticides, particularly where national pesticide regulatory is inexistent or insufficient.

The European regulation no.1107/2009[6], concerning the placing on the market of plant protection products, defines plant protection products as

"[…] products, in the form in which they are supplied to the user, consisting of or containing active substances[7], plant protectant[8] or synergists[9], and intended for one of the following uses:

(a) protecting plants or plant products against all harmful organisms or preventing the action of such organisms, unless the main purpose of these products is considered to be for reasons of hygiene rather than for the protection of plants or plant products;

(b) influencing the life processes of plants, such as substances influencing their growth, other than as a nutrient;

(c) preserving plant products, in so far as such substances or products are not subject to special Community provisions on preservatives;

(d) destroying undesired plants or parts of plants, except algae unless the products are applied on soil or water to protect plants;

(e) checking or preventing undesired growth of plants, except algae unless the products are applied on soil or water to protect plants."

Pesticides may be categorized according to their function (insecticides, herbicides, fungicides, rodenticides, molluscicides, nematicides, plant growth regulators and others), their chemical structure (e.g., organochlorines, organo-phosphates, carbamates, phenoxy acids), or their physical state. They may be inorganic (e.g., sulphur, sodium arsenate, chlorine) or organic, natural (e.g., pyrethrin, nicotine) or synthetic, biological (e.g., bacteria, viruses) or chemical. Commonly used pesticides include i) insecticides to control termites, ants, mosquitos, and cockroaches; ii) herbicides to control weeds and un-wanted plants; iii) rodenticides to control mouse and rat infestations; and iv) fungicides to prevent

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[6] The Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC.

[7] "Substances, including micro-organisms having general or specific action against harmful organisms or on plants, parts of plants or plant products" (European Parliament, 2009).

[8] "Substances or preparations which are added to a plant protection product for the purpose of annulling or reducing the phytotoxic effects of the plant protection product on certain plants" (Inserm (dir.), 2013).

[9] "Substances or preparations which, although having little or no activity, may enhance the activity of the active substance (s) present in a plant protection product" (Inserm (dir.), 2013).

molds and other plant pathogens (Aktar et al., 2009; American Medical Association, 1997). These characteristics may influence the exposure patterns of occupational users and the general population and their possible health effects.

1.1.2. Definition of Exposure, dose and concentration

To deal with the (positive and negative) effects of pesticides, it is necessary to bring in other concepts, like exposure, dose, concentration and toxicity.

Exposure is defined as "the fact of experiencing something or being affected by it because of being in a particular situation or place"(Cambridge Dictionary, 2018), "The state of having no protection from something harmful" (Oxford Living Dictionary, 2018), "the state of being put into a situation in which something harmful or dangerous might affect you" (MacMillan Dictionary, 2018). In the field of economic disciplines, in particular in occupational safety, "exposure" is defined as "State of being vulnerable to work environment hazards through contact, inhalation, ingestions, or any other route" (BusinnesDictionary, 2018).

For the expology discipline, exposure is a deceptively simple concept, defined as contact at a body boundary between a person and an environmental stressor (biological, chemical, or physical) over time (Ott 1985; Sexton et al. 1995; Zartarian et al. 2005; Hoppin et al. 2006). This simple definition masks the fact that a quantitative exposure analysis requires collection and analysis of multiple parameters, such as concentration and duration of exposure, as well as exposure factors that affect contact rates and, therefore, determine the magnitude of exposure. Man may be exposed to pesticides in a variety of ways; at different dose levels and for varying periods of time (Jeyaratnam, 1990) (Figure 1).

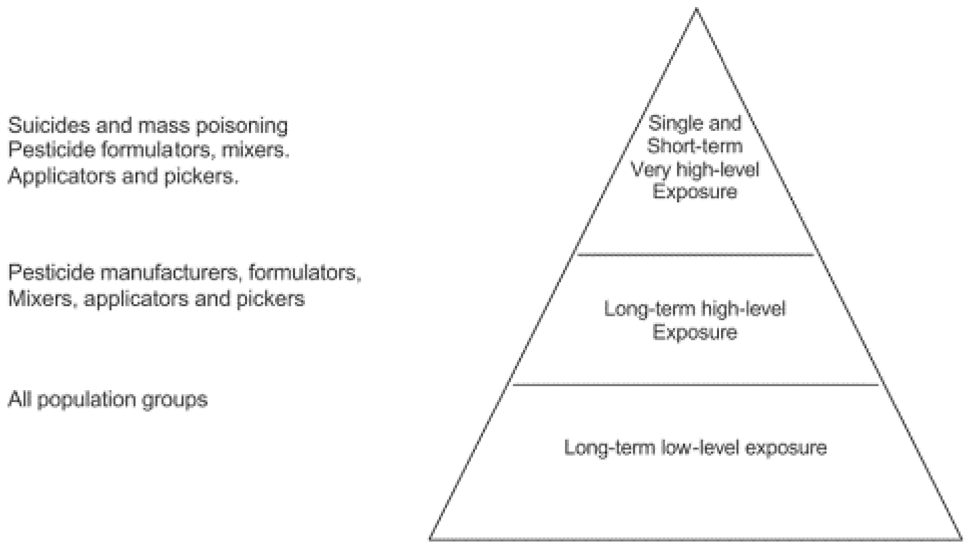

Figure 1 - Different populations are exposed to various kinds of exposure to pesticides

A description of exposure for a particular route (i.e., inhalation, ingestion, or dermal absorption) must include at least the following two related attributes: concentration of the pesticide in the carrier medium and the duration of contact. Therefore, exposure to pesticides in the environment requires not only the presence of the pesticide, but also that an individual comes in contact with the pesticide at a specific time in a specific place. If there is no possibility of contact, there is no exposure.

Most human pesticide exposures occur without apparent adverse health effects (Gilden et al., 2010). When illness occurs, it often involves acute exposures resulting from misapplication or negligence (Clarke et al., 1997). Intentional intoxications and suicides also occur. The severity of illness depends upon the physiological activity of the pesticide ingredients, the dosage received, the route and duration of exposure, and the specific host characteristics. Acute symptoms generally appear within minutes to hours after exposure and range from relatively mild head-aches, fatigue, skin rashes, eye irritation, and general flu-like symptoms to more severe chemical burns, paralysis, and even death.

Dose is a term borrowed from chemistry. It refers to levels of active substance measured within a biological boundary.

Concentration is also a term borrowed from chemistry. It is the amount of pesticide measured in a mass or volume of an environmental medium (Hoppin et al., 2006). Lastly, frequency and duration of exposure are key elements of pesticide exposure assessment, because these variables are used to determine the cumulative dose over time. Frequency describes the number of contacts over a period of time (e.g., contact rate), and duration describes the lengths of these contacts. Exposures to pesticides typically vary over time with specific events such as applications indoors or to nearby fields appearing as spikes in an individual's exposure profile over time, above an individual's background rate of exposure. Thus, estimating an average exposure for an individual may underestimate the impact of peak exposure events.

1.1.3. Definitions about toxicity

Social issue about pesticides comes from the potential "toxicity" of most of the pesticides in use today. It claims for clarification about "toxicity". The main paradox is that to be efficient against pest, one pesticide must be toxic for the pest, so has high potential to be toxic for human beings too.

Toxicity means a physiological or biological property which determines the capacity of a chemical to do harm or produce injury to a living organism by other than mechanical means (FAO, 2003).

In terms of toxicity we must sort out acute and chronic toxicity. A pesticide poisoning occurs when chemicals intended to control a pest affect non-target organisms such as humans, wildlife, or bees. There are three types of pesticide poisoning (see Figure 1). The first of the three (by acute toxicity) is a single and short-term very high level of exposure which can be experienced by individuals who commit suicide, as well as pesticide formulators. The second type of poisoning is long-term high-level exposure, which can occur in pesticide formulators and manufacturers (we will deal with this kind of toxicity in the present work). The third type of poisoning is linked to chronic toxicity. It is a long-term low-level exposure, which individuals are exposed to from sources such as pesticide residues in food as well as contact with pesticide residues in the air, water, soil, sediment, food materials, plants and animals.

1.2.Benefits and hazards of pesticides

Pesticides are ambivalent. We use them because they bring many benefits to human beings (§ 1.2.1), despite they bring health hazards too, especially because of their toxicity (§ 1.2.2). The conditions which favour toxicity becoming damage to human health deserve specific attention (§ 1.2.3)

1.2.1. Benefits of pesticides

The primary benefits are the consequences of the normal pesticides' effects – the direct gains expected from their use. The three main effects result in 26 primary benefits ranging from protection of recreational turf to saved human lives. The secondary benefits are the less immediate or less obvious benefits that result from the primary benefits. They may be subtle, less intuitively obvious, or of longer term. It follows that for secondary benefits it is therefore more difficult to establish cause and effect. Nevertheless, they can be powerful justifications for pesticide use. There are various secondary benefits identified, ranging from fitter people to conserved biodiversity.

The transport sector makes extensive use of pesticides, particularly herbicides. Herbicides and insecticides are used to maintain the turf on sports pitches, cricket grounds and golf courses. Insecticides protect buildings and other wooden structures from damage by termites and woodboring insects. Nevertheless, here, we insist on benefits of pesticides use which are important for agriculture.

Improving productivity

Tremendous benefits have been derived from the use of pesticides in forestry, public health and the domestic sphere – and, of course, in agriculture (Aktar et al., 2009).

In India, food grain production, which stood at a mere 50 million tons in 1948–49, had increased almost fourfold to 198 million tons by the end of 1996–97 from an estimated 169 million hectares of permanently cropped land. This result has been achieved by the use of high-yield varieties of seeds, advanced irrigation technologies and agricultural chemicals (Aktar et al., 2009).

Similarly, outputs and productivity have increased dramatically in most countries, for example wheat yields in the United Kingdom, corn yields in the USA. Increases in productivity have been due to several factors including use of fertiliser, better varieties and use of machinery. Pesticides have been an integral part of the process by reducing losses from the weeds, diseases and insect pests that can markedly reduce the amount of harvestable produce. Webster et al. (1999) stated that "considerable economic losses" would be suffered without pesticide use and quantified the significant increases in yield and economic margin that result from pesticide use. Moreover, in the environment, most pesticides undergo photochemical transformation to produce metabolites which are relatively non-toxic to both human beings and the environment.

Protection of crop losses/yield reduction

In medium land, rice even under puddle conditions during the critical period warranted an effective and economic weed control practice to prevent reduction in rice yield due to weeds that ranged from 28 to 48%, based on comparisons that included control (weedy) plots (Behera and Singh, 1999). Weeds reduce yield of dry land crops (Behera and Singh, 1999) by 37–79%. Severe infestation of weeds, particularly in the early stage of crop establishment, ultimately accounts for a yield reduction of 40%. Herbicides provided both an economic and labour benefit.

Protection of crops after harvest

Pesticides can be employed also in the post-harvest phase. Recently, natural PPPs have taken on an increasing role in this field. Several plant species and their extracts have been found with natural pesticide ability and are used very commonly as a traditional practice to protect the grains from insects in several African and Asian countries (Kumar and Kalita, 2017).

Vector disease control

Vector-borne diseases are most effectively tackled by killing the vectors. Insecticides are often the only practical way to control the insects that spread deadly diseases such as malaria, resulting in an estimated 5,000 deaths each day (Ross, 2005). In 2004, Bhatia wrote that malaria is one of the leading causes of morbidity and mortality in the developing world and a major public health problem in India. Disease control strategies are crucially important for livestock also.

Food quality

In countries of the first world, it has been observed that a diet containing fresh fruit and vegetables far outweigh potential risks from eating very low residues of pesticides in crops (Brown, 2004). Increasing evidence (Dietary Guidelines, 2005) shows that eating fruit and vegetables regularly reduces the risk of many cancers, high blood pressure, heart disease, diabetes, stroke, and other chronic diseases. Lewis et al. (2005) discussed the nutritional properties of apples and blueberries in the US diet, and concluded that their high concentrations of antioxidants act as protectants against cancer and heart disease. Lewis attributed doubling in wild blueberry production and subsequent increases in consumption chiefly to herbicide use that improved weed control.

1.2.2. Hazards of pesticides

Hazards of pesticides are caused by their own toxicity. The effects are different regarding acute (§1.2.2.1) and chronic toxicity (§1.2.2.2.).

1.2.2.1. Acute toxicity

In developing countries, pesticide poisonings from short-term very high level of exposure (acute poisoning) is the most worrisome type of poisoning. However, in developed countries it is the complete opposite: acute pesticide poisoning is controlled, thus making the main issue long-term low-level exposure of pesticides.

The most common exposure scenarios for pesticide-poisoning cases are accidental or suicidal poisonings, occupational exposure, by-stander exposure to off-target drift, and the general public who are exposed through environmental contamination.

Acute pesticide poisoning is a large-scale problem from decades, especially in developing countries:

> *"Most estimates concerning the extent of acute pesticide poisoning have been based on data from hospital admissions which would include only the more serious cases. The latest estimate by a WHO task group indicates that there may be 1 million serious unintentional poisonings each year and in addition 2 million people hospitalized for suicide attempts with pesticides. This necessarily reflects only a fraction of the real problem. On the basis of a survey of self-reported minor poisoning carried out in the Asian region, it is estimated that there could be as many as 25 million agricultural workers in the developing world suffering an episode of poisoning each year"* (Jeyaratnam, 1990).

Pesticide poisoning is an important occupational health issue because pesticides are used in a large number of industries, which puts many different categories of workers at risk. Extensive use puts agricultural workers, in particular at increased risk for pesticide illnesses. Workers in other industries are at risk for exposure as well. For example, commercial availability of pesticides in stores puts retail workers at risk for exposure and illness when they handle pesticide products. The ubiquity of pesticides puts emergency responders such as fire-fighters and police officers at risk, because they are often the first responders to emergency events and may be unaware of the presence of a poisoning hazard. The process of aircraft disinfection, in which pesticides are used on inbound international flights for insect and disease control, can also make flight attendants sick.

Different job functions can lead to various levels of exposure. Most occupational exposures are caused by absorption through exposed skin such as the face, hands, forearms, neck, and chest. This exposure is sometimes enhanced by inhalation in settings including spraying operations in greenhouses and other closed environments, tractor cabs, and the operation of rotary fan mist sprayers.

When thinking of pesticide poisoning, one does not take into consideration the contribution made by its own household. The majority of households in Canada use pesticides while taking part in activities such as gardening. In Canada, in 2015, 97% of household report having a lawn or a garden (Statistics Canada, 2018). 56% of the households who have a lawn, or a garden utilize fertilizer or pesticide (Statistics Canada, 2018). This form of pesticide use may contribute to the third type of poisoning, which is caused by long-term low-level exposure. As mentioned before, long-term low-level exposure affects individuals from sources such as pesticide residues in food as well as contact with pesticide residues in the air, water, soil, sediment, food materials, plants and animals.

Self-poisoning with agricultural pesticides represents a major hidden public health problem accounting for approximately one-third of all suicides worldwide. It is one of the most common forms of self-injury in the Global South. The World Health Organization estimates that 300,000 people die from self-harm each year in the Asia-Pacific region alone (Eddleston and Philips, 2004). Most cases of intentional pesticide poisoning appear to be impulsive acts undertaken during stressful events. The availability of pesticides strongly influences the incidence of self-poisoning. Pesticides are the agents most frequently used by farmers and students in India to commit suicide.

1.2.2.2. Chronic toxicity

For human beings exposed, chronic toxicity itself can lead to different types of disease. Certain environmental chemicals, including pesticides termed as endocrine disruptors, are known to elicit their adverse effects by mimicking or antagonising natural hormones in the body. It has been postulated that their long-term, low-dose exposure is increasingly linked to human health effects such as immune suppression, hormone disruption, diminished intelligence, reproductive abnormalities and cancer (e.g., Bassil et al., 2007; Sanborn et al., 2007).

Cancer

One of the most common end points investigated for health effects of any chemical is cancer. Identification of a causative mechanism for cancer is often problematic due to multiple exposures and long latency periods (Gilden et al., 2010). Many studies have examined the effects of pesticide exposure on the risk of cancer (see e.g., Infante-Rivard and Weichenthal, 2007; Zahm and Ward, 1998). Associations have been found with leukaemia (e.g., Van Maele-Fabry et al., 2010), lymphoma, and brain, kidney, breast, prostate, pancreas, liver, lung, and skin cancers (e.g., Gilden et al., 2010; Infante-Rivard and Weichenthal, 2007; Van Maele-Fabry et al., 2010; Zahm and Ward, 1998). The increased risk occurs with both residential and occupational exposures (McCauley et al., 2006). Increased rates of cancer have been found among farm workers who apply these chemicals. A mother's occupational exposure to pesticides during pregnancy is associated with an increase in her child's risk of leukaemia, Wilms' tumour, and brain cancer (Gilden et al., 2010; Van Maele-Fabry et al., 2010). Exposure to insecticides inside home and herbicides outside is associated with blood cancers in children (Chen et al., 2015).

Neurological effects

Evidence links pesticide exposure to worsened neurological outcomes (Sanborn et al., 2007). The risk of developing Parkinson's disease is 70% greater in those exposed to even low levels of pesticides. People with Parkinson's were 61% more likely to report direct pesticide application than were healthy relatives. Both insecticides and herbicides significantly increased the risk of Parkinson's disease. There are also concerns that long-term exposures may increase the risk of dementia (Klimkina, 2014).

The United States Environmental Protection Agency finished a 10-year review of the organophosphate pesticides following the 1996 Food Quality Protection Act, but did little to account for developmental neurotoxic effects, drawing strong criticism from both inside the agency and outside researchers. Comparable studies have not been done with newer pesticides that are replacing organophosphates.

Reproductive effects

Strong evidence links pesticide exposure to birth defects, fetal death and altered fetal growth (Sanborn et al., 2007). In the United States, increase in birth defects is associated with conceiving in the same period of the year when agrochemicals are in elevated concentrations in surface water. "Agent Orange" has been associated with bad health and genetic effects in Malaya and Vietnam. It was also found that offspring that were at some point exposed to pesticides had a low birth weight and developmental defects.

A number of pesticides including the dibromochlorophane and the dichlorophenoxyacetic acid has been associated with impaired fertility in males. Pesticide exposure resulted in reduced fertility in males, genetic alterations in sperm, a reduced number of sperm, damage to germinal epithelium and altered hormonal function (Sheiner et al., 2003).

Other

Some studies (e.g., Sanborn et al., 2007) have found increased risks of dermatitis in those exposed. Additionally, other studies (e.g., Amaral, 2014; Doust et al., 2014; Gilden et al., 2010) have indicated that pesticide exposure is associated with long-term health problems such as respiratory problems, including asthma, memory disorders and depression. Summaries of peer-reviewed research have examined the link between pesticide exposure and neurologic outcomes and cancer, perhaps the two most significant phenomena among organophosphate-exposed workers.

According to researchers from the National Institutes of Health (NIH), licensed pesticide applicators who used chlorinated pesticides more often than 100 days in their lifetime, were at greater risk of diabetes. One study found that associations between specific pesticides and incident diabetes ranged from a 20 percent to a 200 percent increase in risk. New cases of diabetes were reported by 3.4 percent of those in the lowest pesticide use category, compared with 4.6 percent of those in the highest category. Risks were greater when users of specific pesticides were compared with applicators who never applied that chemical (Montgomery et al., 2008).

Conclusion about toxicity

In most countries, all of the routes of pesticide exposure prevail. Nevertheless, it is worth each country or region to identifying the mode of exposure and resultant hazard which is the most important to its own circumstances. For instance, in the industrialized world, the problem of acute pesticide poisoning has largely been controlled and the main focus of attention is on the possible health effects arising from exposure to low levels of pesticides over a long period of time. Such exposures usually arise from environmental contamination as well as from pesticide residues in food, whereas the situation is quite the reverse in the countries of the developing world (Jeyaratnam, 1990).

1.2.3. How pesticides entail damages to human health

Because of their intended use, most chemical pesticides are considered to be toxic. However, toxicity becomes an issue only when people are exposed to the toxic substance. Exposure can occur through several media, as depicted in Figure 1 - Different populations are exposed to various kinds of exposure to pesticides, and through several routes (Figure 2). Despite different routes of exposure lead to different health problems, deriving from different organs affected by the chemical, the general cause-effect chain between the substance and the health disease does not vary (Figure 3).

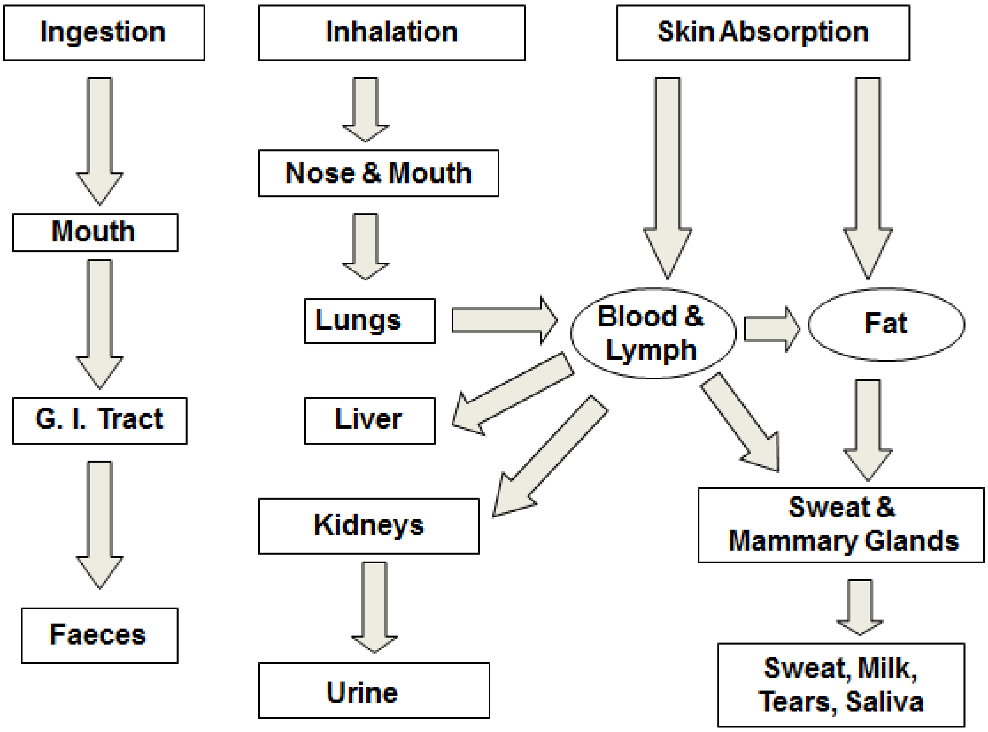

Figure 2 - Various modes of exposure of pesticides and their metabolic route through different organs of the body till their excretion (from Sharma and Goyal, 2014)

The cause-effect chain is composed by an applied substance that implies an exposure, that provokes a reaction of the organism, with consequences being health issue.

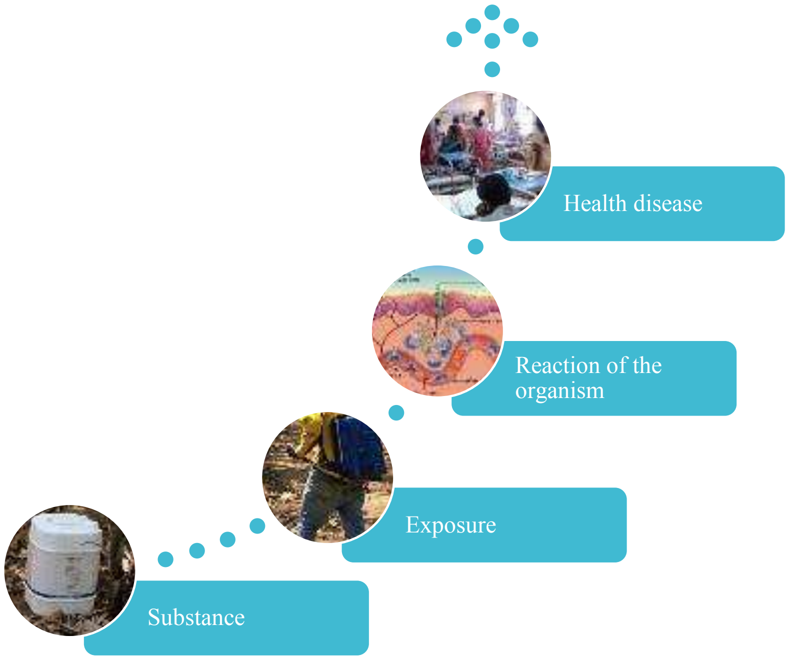

Figure 3 - Consequences of use of pesticide products and steps of the chain of effects after application

The degree of toxicity varies with the type of pesticide product. Most pesticides are available as chemical formulations of ‘‘active’’ and ‘‘inert’’ ingredients. Particular formulations may be applied as liquids, solids, or gases. Active ingredients include more than 800 chemicals with a spectrum of pesticidal properties and effects. Inert ingredients are added to increase the applicability, solubility, or stability of the active ingredients. Whereas active ingredients are required to be listed on pesticide labels, trade secret laws protect the identity of most inert ingredients. This causes concern because some inert ingredients (e.g., toluene, chloroform) are not toxicologically inert and may also pose potential health risks. In fact, numerous studies indicate that inert ingredients may enhance the toxicity of pesticide formulations to the nervous system, the cardiovascular system, mitochondria, genetic material, and hormone systems (Cox and Surgan, 2006).

If the credits of pesticides include enhanced economic potential in terms of increased production of food and fibre, and amelioration of vector-borne diseases, their debits have resulted in serious health implications to man and to environment, as highlighted in § 1.2.2. Nevertheless, risks for human health are different regarding different situations of exposure. We examine here exposure through food commodities, exposure from environment, and we underpin that agricultural workers are among the most exposed targets regarding health damage caused by pesticides (Aktar et al., 2009; Inserm (dir.), 2013).

1.2.3.1. Exposure through food commodities

Many cases of poisoning through food commodities have been reported in the past (e.g., Birch et al., 2011). Today in developed world, the exposure level in carefully monitored. In 1997, in the field of the programs entitled 'Monitoring of Pesticide Residues in Products of Plant Origin in the European Union', the residues of 13 pesticides (acephate, carbendazin, chlorothalonil, chlopyriphos, DDT, diazinon, endosulfan, methamidophos, iprodione, metalaxyl, methidathion, thiabendazole, triazophos) were assessed in five commodities (mandarins, pears, bananas, beans, and potatoes). Some 6,000 samples were analysed. Residues of chlorpyriphos exceeded Maximum Residue Levels (MRL)[10] most often (0.24%), followed by methamidophos (0.18%), and iprodione (0.13%). Regarding the commodities investigated, around 34% contained pesticide residues at or below the MRL, and 1% contained residues at levels above the MRL. In mandarins, pesticide residues were most frequently found at levels at or below the MRL (69%), followed by bananas (51%), pears (28%), beans (21%) and potatoes (9%). MRLs were exceeded most often in beans (1.9%), followed by mandarins (1.8%), pears (1.3%), and bananas and potatoes (0.5%). Estimation of the dietary intake of pesticide residues (based on the 90th percentile) from the above-mentioned commodities, where the highest residue levels of the respective pesticides have been found, shows that there is no exceeding of the Acceptable Day Intake (ADI) whatever the pesticides and commodities studied. We will not deepen the topic of exposure through food.

1.2.3.2. Exposure through environment

Pesticides can contaminate soil, water, turf, and other vegetation. In addition to killing insects or weeds, pesticides can be toxic to other organisms including birds, fish, beneficial insects, and non-target plants. Insecticides are generally the most acutely toxic class of pesticides, but herbicides can also pose risks to non-target organisms (Aktar et al., 2009). Many studies (e.g., Birch et al., 2011) argument loss of biodiversity because of chronic toxicity of pesticides in use. Nevertheless, we will not deepen this topic, as we focus directly on human exposure.

[10] For more information on European safety assessment of Maximum Residue Levels in (MRLs) in foods, see: http://www.efsa.europa.eu/en/mrls/mrlteam.htm .

1.2.3.3. *Who is exposed?*

A widespread use of pesticides over the past several decades has led to their dissemination in all environments and, some of them, to persistence over the long term. Indeed, numerous data attest to their presence in the biological fluids of human populations, even after their ban, for the most persistent. Although the availability and use of pesticides is governed by regulations, the issue of risk still remains (Inserm (dir.), 2013).

As reported by the Inserm[11] report (2013), in 2008 in France, about 90% of the tonnages of pesticides sold were used for agricultural purposes and 10% for non-agricultural uses: maintenance of road and rail infrastructure, green spaces, sidewalks, gardening, treatment of indoor spaces, etc. Most of pesticides used are plant protection products, especially in agricultural areas.

The question is even more crucial for farmers and for all professionals who have to manipulate, sometimes massively, many substances throughout their careers.

Aktar et al. (2009) affirm that the high-risk groups exposed to pesticides include pesticides production workers, formulators, sprayers, mixers, loaders and agricultural farm workers. In fact, during manufacture and formulation, the possibility of hazards may be higher because the processes involved are not risk free. In industrial settings, workers are at increased risk since they handle various toxic chemicals including pesticides, raw materials, toxic solvents and inert carriers. The statement is confirmed by data reported in the Inserm collective appraisal report (2013). In Annex 5, they assessed analysed studies on exposure to pesticides, and the occurrence of pathology in adults and children. In this analysis, they reported a positive association between occupational exposure to pesticides in agriculture and various pathologies in adults (Table 1). In particular, as reported in the following table, pesticide applicators are explicitly highlighted as a population specifically affected by the consequences of pesticide exposure.

[11] The *Institut national de la santé et de la recherche médicale* is the French National Institute of Health and Medical Research.

PATHOLOGIES	POPULATIONS AFFECTED BY AN EXCESS OF SIGNIFICANT RISK	PRESUMPTION OF A LINK
LYMPHOME NON HODGKINIEN (LNH)	Farmers, pesticide applicators, production workers	Strong presumption
PROSTATE CANCER	Farmers, pesticide applicators, production workers	Strong presumption
MULTIPLE MYELOMA	Farmers, pesticide applicators	Strong presumption
PARKINSON DISEASE	Professional and non-professional	Strong presumption
LEUKAEMIA	Farmers, pesticide applicators, production workers	Medium presumption
ALZHEIMER DISEASE	Farmers	Medium presumption
COGNITIVE DISORDERS	Farmers	Medium presumption
IMPACT ON FERTILITY	Occupational populations exposed	Medium presumption
HODGKIN'S DISEASE	Agricultural Populations	Low presumption
CANCER OF THE TESTICLE	Agricultural Populations	Low presumption
BRAIN TUMOURS (GLIOMAS MENINGIOMAS)	Agricultural Populations	Low presumption
SKIN MELANOMA	Agricultural Populations	Low presumption
AMYOTROPHIC LATERAL SCLEROSIS (ALS)	Farmers	Low presumption
ANXIETY DISORDERS	Farmers, farmers with a history of acute poisoning, applicators	Low presumption

Table 1 - Positive association between occupational exposure to pesticides and pathologies in adults (adapted from Inserm, 2013)

From the research conducted by Plak (2015) the agriculture health studies have often focused on the following topics:

- Pesticide exposure study aimed at measuring exposure to pesticide among private pesticide applicator, pesticide workers and commercial applicators;
- Orchard fungicide exposure study, that focuses on farmers who personally apply it;
- Farmers exposed and greenhouse workers.

Assessing the magnitude of the health risk from pesticide exposures in the workplace can be difficult because exposures are usually intermittent, pesticide metabolites have a short half-life, and biomarkers of exposure are often nonspecific to the exposure. Assessing health risk from pesticide exposures in the general environment is even more challenging (Alavanja et al., 2013).

Nonetheless, the available scientific evidence does strongly suggest that pesticides cause cancer in both those who use the pesticides directly and those who are exposed because of applications that others make. The problem may well be more extreme in developing countries where regulatory controls are weaker or non-existent. Moreover, in developing countries, methods of handling pesticides and safety practices reflect the poor knowledge and understanding of the health risks of pesticide exposure (Jaga and Dharmani, 2003).

In occupational settings, persons working directly and frequently with pesticides are groups with the highest risk of exposure (Damalas and Eleftherohorinos, 2011; Ye et al., 2013). Accidental spills of pesticides, leakages, incorrect uses of equipment, incorrect application techniques and non-compliance with safety guidelines, are the leading causes of occupational pesticide exposures (Damalas and Eleftherohorinos, 2011; Jaga and Dharmani, 2003).

Considering the link between occupational exposure and health diseases, and the specific risk for pesticide applicators, we decided to focus our attention on agricultural workers[12]**,** particularly on professional operators (in this work "operators")[13].

Pesticides enter the body to a large extent via inhalation and dermal absorption, mainly during application, but also, for example, during the preparation of pesticides, and the cleaning and repairing of the application equipment.

For all the reasons listed above, we decided to handle this kind of problem and to focus on the operators' pesticides exposure.

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[12] *"Workers are: persons who, as part of their employment, enter an area that has previously been treated with a PPP or who handle a crop that has been treated with a PPP."* (EFSA, 2010).

[13] "*Operators are: persons who are involved in activities relating to the application of a plant protection product (PPP); such activities include mixing/loading the product into the application machinery, operation of the application machinery, repair of the application machinery whilst it contains the plant protection product, and emptying/cleaning the machinery/containers after use. Operators may be either professionals (e.g. farmers or contract applicators engaged in commercial crop production) or amateur users (e.g. home garden users).*" (EFSA, 2010).

1.3. Viable solutions?

As explained above, toxicity entails damage only if there are particular exposure conditions. To mitigate health damages caused by toxicity of pesticides, two routes are therefore open: eliminating toxicity by removing pesticides (§ 1.3.2) or buffering exposure to pesticides (§ 1.3.3). First, we check the different actors which are involved in finding solutions to mitigate pesticides hazards (§ 1.3.1).

1.3.1. Actors involved in mitigating pesticides hazards

Many actors are involved in mitigating pesticides hazard, with different levers for action.

1.3.1.1. The role of governments

The ultimate responsibility to control the use of pesticides to minimize health hazards devolves to national governments. They must continue, and whenever necessary strengthen, health education programs among pesticide users, particularly to ensure safe practices. Educational and informational programs can be helpful for professional applicators, the general public, and health care professionals by improving their knowledge about the risks and benefits of pesticides. With such knowledge, individuals may be able to make more informed decisions about the potential hazards of pesticides used at home, at work, and in the community (American Medical Association, 1997).

Though many countries have enacted legislation, enforcement remains insufficient. As an immediate corrective measure, it may be appropriate to consider selective enforcement or selective legislation to control those pesticides considered to be most hazardous. For this purpose, the WHO document "Recommended classification of pesticides by hazard and guidelines to classifications" highlights that the pesticides classified extremely hazardous and highly hazardous should be identified for stricter controls.

Further methods in order to aid prevention of acute pesticide poisoning, concerning both accidental death and suicides, could be the national governments to control accessibility. If use of the most toxic pesticides is restricted, it could reduce deaths. There could also be designated locations in rural living areas and cities used to safely store toxic pesticides, in order to gain control over usage.

1.3.1.2. The role of international agencies

The international agencies, particularly WHO and the International Labour Organisation (ILO), have contributed a great deal in their attempts to control pesticide poisoning. They should continue their efforts, with particular emphasis on education and training on safety in the use of pesticides (International Labour Organisation, 1991; World Health Organisation, 1991) and applied research activities. They should play the role of intermediary for the involvement of agrochemical industries in safety activities.

1.3.1.3. The role of the agrochemical industry

The agrochemical industries are often not included in control programs. This is a great drawback which needs to be rectified, as these organizations can contribute significantly to the control of poisoning, particularly in the following areas (Jeyaratnam, 1990):

- research into developing appropriate personal protective equipment for tropical countries;
- prevention of marketing of pesticide mixtures;
- maintenance and repair of spray equipment;
- research to develop hazard-free spray equipment;
- use of safe pesticide containers which are unlikely to be accident prone.

1.3.1.4. The role of farms managers

As highlighted before (§ 1.2.3) agricultural workers are among the populations at risk. So, farms managers can play an important role regarding the health of the agricultural workers involved in the farm work. Depending on the crop, on the technics in use, and on certain precautions, the exposure of farm workers may vary, as illustrated in the next paragraphs.

Many actors are liable to act in the field. We will favour the preventive actions which can be handled by farms managers, as they are the most relevant for our topic.

1.3.2. Eliminating pesticides toxicity by removing pesticides

In intensive agricultural production systems, concepts in crop protection changed from destruction of pests by the use of pesticides, to pest management. Pest management draws on techniques based on the improved knowledge of pest dynamics and their natural enemies, and the interaction between pests and crops under the influence of cropping practices (Kropff et al., 1995). It is therefore necessary to combine cultural, genetic, biological, physical and chemical control methods to manage pests, through Integrated Pest Management (IPM) strategies, in order to maintain the pest population levels below those causing economic losses (Birch et al., 2011). Studies on the effects of alternative control methods mostly concern a major pest (monospecific approach) while farmers have to manage an injury profile in a given field (Savary et al., 2000). The research has focused on the effect of one (or a few) control method(s), but farmers usually combine several operations (which may have only partial effects) to limit pest development. In order to reduce the reliance of cropping systems on pesticides, it is therefore necessary to develop tools to help the ''vertical integration'' (combination of several control methods) and the ''horizontal integration'' (simultaneous management of several pests) of IPM strategies (Aubertot and Robin, 2013).

The radical solution to eliminate issues caused by toxicity of pesticides is to remove pesticides themselves, when possible. The replacement of pesticides is in the hand of the farm managers, often supported or committed by public institutions. Several substitution technics are briefly depicted below.

Several methods are available for the management of pests, but chemical control (using pesticides) is the most used today. It may be associated with the genetic control, which consists of using plants selected for their resistance, their tolerance and their physiological characteristics to reduce losses due to pests. Among the works pertaining to varietal resistance or tolerance, some are interested in the cultural control (reduction of the seedling rate and nitrogen fertilization) (Loyce et al. 2008; Meynard et al. 2009), others pertain to the physical characteristic of plants (Garin et al. 2014; Robert et al. 2008).

The biological pest control uses living organisms to prevent or reduce the damage caused by pests. In literature, we distinguished i) methods based on the introduction of a new species in an environment, which proceed through the releases of an enemy of the pest (inundative struggle for massive releases or releases inoculative for small quantities) and ii) environmental manipulation that aims to encourage the enemies of the pest naturally present (biological control by conservation).

The biotechnical control concerns methods using biological phenomena or phenomena of biological origin, but no living organisms. Examples are the sexual confusion, disrupting the reproduction of insects by diffusion of pheromones, or the induction of plant resistances by elicitors which activate its natural defence mechanisms.

The development of molecular technologies has opened new research perspectives for the elaboration of pests control methods. Research in this field pertains especially to the interactions between plant and pathogen and their genetic mechanisms, the key genes analysis controlling insect development and reproduction, the insecticides and fungicides study (Aubertot et al., 2005).

Physical control consists in use of mechanical, thermal, electromagnetic or pneumatic means. It can also be used in particular by mechanical weeding or use of physical barrier against the insect pests. Physical and biological pest control techniques can be implemented to reduce the initial stock pests. In the culture developing phase, avoidance or escape strategy can be mobilized (e.g. avoiding clashing between the phase of contamination by the parasite and the sensitivity period of culture or developing crops, that can discourage the parasites attack). A third way is to reduce the damage at the contact moment between culture and pests, increasing culture competitiveness and avoiding favourable conditions for pests' development and propagation (e.g. operating on seedling rate or varietal choice) (Attoumani-Ronceux et al. 2011; Baccar et al. 2011).

Finally, the cultural control adjusts the cultivation system to limit damage caused by pests. The cultural control alters rotations and manages differently elements of the cropping system: tillage, seedling date and density, fertilization. Works mobilizing these methods are generally focused on the redesign of the cropping systems.

At supra plot scale, the spatial organization of crops can also be mobilized to control pests by limiting their spread (mosaic of cultures, hedges) or by promoting their regulation by auxiliary plants (hedges, grass strips, refuge areas). Some projects have addressed this aspect, e.g. Tixier et al. (2010) for the management of the banana weevil.

Research works developed in this field allowed to test different solutions for the substitution of pesticides with the physical, biotechnical and biological pest control. The sustainability assessment of these alternative practices remains a key challenge, as the issue of their juridical status, in particular regarding the European Regulation[14].

[14] The Regulation 1107/2009, applicable from June 2011, aims "to ensure a high level of protection of both human and animal health and the environment, and at the same time, to safeguard the competitiveness of Community agriculture", and to define the conditions.

Unfortunately, elimination of pesticides is not possible in all the agronomic cases. Sometimes, there is no other solution than using pesticides, e.g. in tropical climate, it is very difficult to grow bananas without using pesticides against black Sigatoka. Black Sigatoka is one of the four major diseases causing very serious concerns and losses, with Fusarium wilt tropical race 4 (TR4), banana bunchy top disease, and banana Xanthomonas wilt (BXW) (Abadie et al., 2010; Dale et al., 2017). Polidoro et al. (2008) interviewed Costa Rican banana producers that ranked black Sigatoka as the first or second most important agricultural pest. Nevertheless, the other route is always open. It is buffering exposure of people to pesticides.

1.3.3. Buffering exposure to pesticides

Accidental poisonings can be avoided by proper labeling and storage of containers. To reduce the potential for adverse effects, national, federal and international laws require that all pesticide labels provide information about the proper use of the product. Signal words (e.g., ‘‘Danger’’ ‘‘Caution’’) and precautionary statements (e.g., ‘‘Harmful if swallowed’’) are included to prevent acute health effects.

The usual way to buffer exposure to pesticides in farm work is to make workers wearing personal protective equipment (PPE) when exposed to pesticides. When handling or applying pesticides, exposure can be significantly reduced by protecting certain parts of the body where the skin shows increased absorption, such as the scrotal region, underarms, face, scalp, and hands. Unfortunately, it is noticeable that the PPE are not always compatible with comfort of workers, especially in Southern countries (e.g., Feola and Binder, 2010). For this reason, among others, some farm workers do not wear suitable PPE at all, or do not wear nor use them adequately (to be protected enough). In fact, the extent to which workers health can be damaged by pesticides depends on the level of exposure, and correlatively depends on the extent workers correctly wear their PPE. Nevertheless, the level of exposure is linked with the process by which crops are cultivated (so-called “cultivation system”), as we will explain it in the next paragraph. Soon, we will turn back to this issue, which is central for the thesis works.

1.3.3.1. Problem: Redesigning cultivation systems to reduce exposure

From the knowledge and experiences quoted in the paragraphs above, it is clear that the design of the cultivation systems influences the damage on workers’ health because of pesticides, either while decreasing pesticides uses (§ 1.3.4.1), or while buffering exposure (§ 1.3.4). We provide a detailed example of redesign of cultivation system for the bananas cropping systems in French West Indies (tropical system), in Annex 1.

1.3.3.2. Decreasing pesticides use by redesigning cultivation systems

The *production situation* is the physical, chemical and biological components (except the crop itself), of a given field (or agroecosystem) and its environment, as well as socio-economic drivers that affect farmer's decisions. In a given production situation, a farmer can design several cropping systems according to his/her goals, knowledge, cognition and perception of socio-economic and technological drivers as well as the physical, biological, and chemical environment (Aubertot and Robin, 2013).

In order to help design cropping systems, modelling is a key tool (Debaeke et al., 2009).

Figure 4 schematically represents an *agroecosystem*. The farmer designs cropping systems that will achieve social, economic and environmental performances, as a function of the production situation. In particular, the "injury profile" (Figure 4) can be defined as "a dynamic vector of the main injuries affecting the crop" (Aubertot and Robin, 2013).

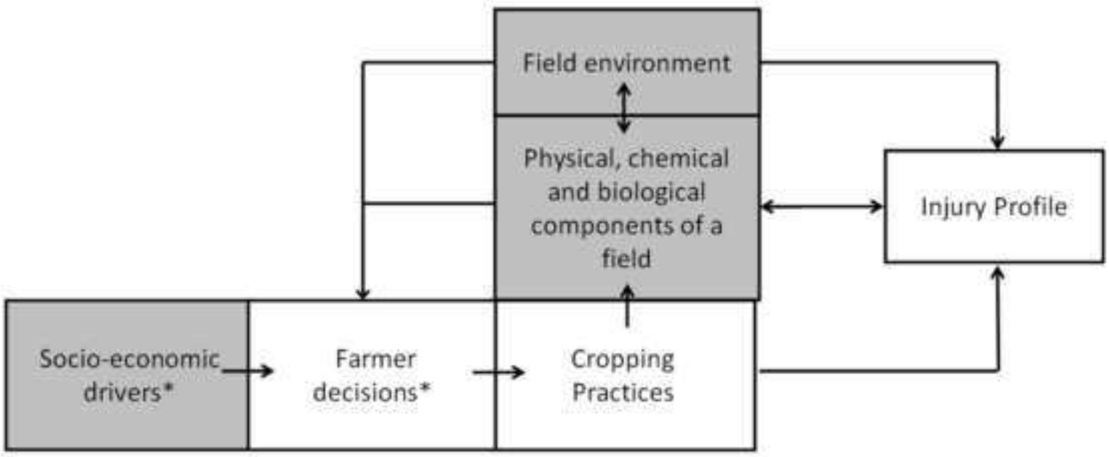

Figure 4 - Schematic representation of an agroecosystem and its drivers (from Aubertot and Robin, 2013)

The term "*cropping system*" refers to "a set of management procedures applied to a given, uniformly treated area, which may be a field, part of a field or a group of fields" (Sebillotte, 1990). This covers many technical operations, for instance, the choice of the crop sequence, cover cropping, cultivar, tillage practices, date and density of sowing, rate of fertilisation and chemical pest control. The term "system" is used here because these technical choices are inter-dependent (Meynard et al., 2003).

Actual cultivation system (short rotations, use of productive varieties but few disease resistant, high density seedling and high fertilization) are structurally pesticides-dependents. As part of an integrated protection and production, a significant reduction of their use requires rethinking the construction of these systems, by introducing in a combined way several techniques (each with partial efficacy) allowing the creation of unfavourable conditions for development of pests (Aubertot et al. 2005; Butault et al. 2010). Rather than fight the pest population when already developed, the focus is on limiting population growth itself (Lucas, 2009). The different strategies evocated before (§ 1.3.2) have to be combined. While the chemical control is a "homogeneous" solution (for each problem we have one given chemical solution), a unique techniques' combination doesn't exist which would be adapted to all the plantation farm plots (Meynard, 2008; Meynard and Girardin, 1991). Practices combinations have to be adapted to each production situation (Aubertot and Robin, 2013).

1.3.4. Buffering exposure to pesticides by redesigning cultivation systems

When it is not possible to give up use of pesticides, it is nonetheless possible to mitigate the exposure of workers to pesticides. Measures stem from simple management practices to comprehensive redesign of the cultivation system.

Exposure can be buffered by simple management practices: in the work management field, the plantation manager may decide to assemble teams of workers trained for handling pesticides. If the manager wants to operate at company level he/she can organize training course on pesticides handling practices and health risks linked to pesticides, addressed to all company's workers. He/she can also decide to subcontract pesticide application to a service provider. In this way, he/she is relieved from providing instruments to protect operators (e.g., PPE buying and carrying out policies to encourage operators to wear them).

In case the manager wants to operate also on workers exposure (and not only on the exposure of operators) he/she can encourage workers to exit from the plot when it is treated, or he/she can decide to treat when workers are not in the plantation (e.g., on Sunday, by night, etc.).

The actual measures to protect workers in the field are warning them when plane is arriving to spray the fields, management of re-entrance in the field, collect of used pesticides packaging etc. The measures to protect specifically operators are mastering good state of PPE, replacing the old PPE as often as needed, training for operators (for them to become aware of the risks), allocating specific premium for operators wearing PPE, mastering the suitable wear of PPE etc.

Sometimes, the change may affect the cultivation system itself. For instance, it can be changing the pesticide application mode (e.g. from aerial to terrestrial application), changing the nature of the pesticides in use etc. More often, the cultivation system is redesigned by combination of some among the simple management practices and some new practices for pest fighting.

1.4. General research question

In the present state of knowledge, we must acknowledge that it is not always possible to give up pesticides. Nevertheless, we make the assumption that it is possible to reduce pesticide use in agriculture and/or to reduce workers exposure without the system to collapse, by reconceiving cultural systems. It is therefore possible to "redesign the cropping systems to reduce exposure to pesticides". The idea is to redesign the cultivation system regarding the potential damage caused to operators' health. To achieve such a purpose, it is necessary to be able to distinguish between different cultivation systems according to this criterion alone (potential damage to operators' health because of pesticides). The necessity for distinction among cultivation systems is the reason justifying our general research question:

General research question: "How to distinguish cropping systems regarding their effects on farm operators' health due to pesticides?"

The general research question entails that we must explore the following sub-questions:

- How to distinguish different cropping systems?
- What is the link between cropping system variations and exposure variations?
- What are the current methods to assess farmworkers health?

The expected results are to prepare the way for building a decision support tool, allowing managers to distinguish between various cropping systems regarding the criterion of damage on farmworkers health because of pesticides. The availability of a simple but reliable pesticide risk indicator would be particularly relevant (Feola et al., 2011). The main characteristics of this new tool ought to be the following: i) it takes into account the real practices implemented by farmworkers (including "bad" practices), ii) data gathering is simple and iii) processing of data is rapid. Here are the specifications for the future tool.

The tool may be used to assess consequences of changes in both the annual programme and the multi-year cycle of one new crop/plantation. This assessment may be performed either per ha, or per parcel, or per the whole surface of the crop at farm level. It will be possible to assess product and/or application technique variation, and/or cultivation system variation. At least, the tool will be suitable either for evaluation of existing cultivation systems, or for evaluation of planned new cultivation systems.

We therefore collect knowledge about the three questions above. The outputs are presented in the next section.

Chapter 2: The state of the art regarding of cropping systems differentiation according to workers' health

In this section, we present the results of the systematic reviews implemented to answer the three research sub-questions defined above (§ 1.4). We are dealing with the discrimination between different cropping systems (§ 2.1), with the link between cropping system and exposure variations (§ 2.2), and with the current methods to assess farmworkers health (§ 2.3). We will also address two families of methods: Environmental Life Cycle Assessment (§ 2.4) and Risk Assessment (§ 2.5), before the concluding paragraph (§ 2.6).

2.1. How to draw a distinction between different cropping systems?

We are interested by differentiating between different technical itineraries (ITK) of the same crop. A "technical itinerary" (ITK) can be defined as the logical and ordered sequence of cultural practices (Aubertot et al., 2011; Ferraton and Touzard, 2009) applied to a crop or to a combination of crops, from the land preparation to harvest (Ferraton and Touzard, 2009). In general, after the harvesting phase, other operations are realised on the parcel (e.g. animals brought to graze harvesting residues) or on the product (e.g. transport, storage, transformation, selling operations). These are not part of the cultural ITK (Ferraton and Touzard, 2009). The value of the ITK concept is that it focuses on two key points: on one hand it supports the ideas of consistency and interaction ("logical and orderly combination") (AgroParisTech 2004) between the technical operations of the farmer (Aubertot et al., 2011), on the other hand it implies that there may be different ways to manage a crop depending on the fixed objective (AgroParisTech 2004). The variability of the ITK is function of time and space (which doesn't allow to establish a detailed "average" ITK in advance).

In general, when designing an ITK, the crop manager also plans some practical actions that might be harmful for human health (HH), albeit he/she is not able to anticipate it with precision. The practical actions take place at different "scales" of the ITK. Here we face the problem of the scarcity of terminology from agronomic disciplines, regarding the possible scales for changes in an ITK. From the research carried out until this moment, we notice that all the cases mentioned above are referred, generically, as a "change of ITK". A particular consensual terminology is still lacking, which would allow us to make a distinction in the nature of the "change of ITK" (product, application method, cultivation system, etc.). To simplify, in the framework of this PhD work, we consider three major ITK variations and we name them as such:

- We can change the ITK by variation of the product (e.g., pesticides) used. For instance, in banana plantation, an insecticide (e.g., Cadusafos) may be replaced by another insecticide (e.g., Dursban). This entails a variation of the ITK that we call change in "product ITK".
- We can change the ITK by variation in the method of applying a product (e.g., plane vs. cannon). This entails a variation of the ITK that we call change in "applying ITK".
- We can change the ITK by variation in cultivation system, e.g., we can put other crops among the banana plants (as in French West Indies) or to weed between the banana plants (as in Costa Rica). This entails a variation of the ITK, that we call change in "cultivation ITK".

We will use the nomenclature of changes above when we screen the methods prone to provide evaluation of changes in ITK, regarding human health.

All these possible variations in the crop system have an immediate consequence at parcel level, but can also have consequences in the mid/long-term at exploitation and watershed level (e.g., impacts on population living downstream a river polluted by chemicals). We will do not consider the impacts at watershed level, but only impacts on farmworkers at farm level.

2.2. What are the links between ITK variations and exposure variations?

Here, we have to take into consideration two groups of workers: the operators and the farm workers.

The risks of exposure related to the use of pesticides in agricultural environments concern both operators and workers. Operators may be exposed in several situations during the professional tasks (e.g., storage, preparation, spreading, and cleaning of tanks). In agricultural environments, the tasks of re-entry into treated fields or contact with contaminated surfaces are exposing situations for workers, that must be taken into account and studied. For these tasks, the awareness of the risk is low (little or no information on the products used) and is accompanied by a lack of wearing protective equipment (Inserm (dir.), 2013).

We notice that the basic technic to collect data about the exposure of operators relies on sticking patches on the operator garment, monitoring the deposition of pesticides, and checking the situations where the protection is broken (EFSA, 2010; Hoppin et al., 2006; Navarro et al., 2011).

The studies analysing the health adverse effects related to the cultivation of a specific culture are limited. Furthermore, no studies investigating the workers' adverse health effects in relation to different cultivation techniques have been found. Nevertheless, we discuss below the variations in exposure caused by variations of product ITK (§ 2.2.1), caused by variations of applying ITK (§ 2.2.2), or by other variations (§ 2.2.3).

2.2.1. Variations of product ITK

The causes leading to change the pesticides product itself are many (e.g., for cost reducing policies, certification restriction, voluntary elimination of a specific product, evolution of national and/or international regulations). When one/several pesticides are replaced by another/several others, the formulations (powder, liquid etc.) can vary also.

It is noticeable that field exposure studies have shown that in occupational settings, the main route of exposure is dermal exposure (Adamis et al., 1985; Inserm (dir.), 2013). For example, in Durham and Wolfe (1962) dermal exposure to DDT during apple treatment was evaluated at 271 mg/man/hour and respiratory exposure at 0.12 mg/man/hour only. Another example was provided by Adamis et al. (1985) (Table 2) and will be deepened in the next paragraph (§ 2.2.2). Furthermore, the properties of retention (Inserm (dir.), 2013) and absorption (Singh and Morris, 2011) of the skin that depend, both from the physicochemical properties of the active substances, both from individual characteristics (such as sudation, dilation of blood vessels in high heat, etc.). For this reason, when the additives alone vary, this change modifies the exposure of operators also (Inserm (dir.), 2013).

So, because of the differences in physicochemical properties of different pesticides, changing the product ITK entails changes in exposure.

2.2.2. Variations of applying ITK

The application route may change for many reasons: for regulation reasons (e.g. aerial application becomes forbidden), to use a new product whose application route is different from the usual ones, to prevent new disease etc. The prohibition of aerial treatment in French West Indies is a remarkable example of the change in exposure expected from the new regulation. Inserm (dir.) (2013) affirms that the risk of contamination during the application of pesticides (both for inside and outside application) is very dependent on the type of material used and of the characteristics of the product (liquid, powder, etc.).

Adamis et al. (1985) conducted a study on applicators and operators in greenhouse tomato spraying operations (two types of spraying technics). The measured exposure was not homogeneous according to the areas of the body and depended, in particular, on the tasks performed. Applicators had contamination on the hands, arms and legs. The importance of contamination depends on the application method of the pesticides (Table 2). Other workers were exposed (through re-entry spots) mainly on the hands and to a lesser extent on the legs (Table 3).

PESTICIDE ACTIVE INGREDIENT	SPRAYING TECHNIQUE	RESPIRATORY EXPOSURE (mg/h)	DERMAL EXPOSURE (mg/h)
PIRIMIPHOS-METHYL	I	0.165 ± 0.12	424.8 ± 34.5
	II	0.039 ± 0.01	44.3 ± 16.9
DIMETHOATE	I	0.059 ± 0.01	346.0 ± 43.6
	II	0.001 ± 0.001	10.5 ± 7.5
PERMETHRIN I	II	0.004 ± 0.003	3.9 ± 0.7

Table 2 - Degree of respiratory and total dermal exposure of applicators in function of different spraying techniques (adapted from Adamis et al., 1985)

MATERIAL	SPRAYING TECHNIQUE	OPERATORS	WORKERS
PIRIMIPHOS-METHYL	I	0.31 % ± 0.03	0.06 % ± 0.01
	II	0.03 % ± 0.01	0.01 % ± 0.006
DIMETHOATE	I	0.71 % ± 0.10	0.06 % ± 0.01
	II	0.02% ± 0.01	0.003 % + 0.001
PERMETHRIN	II	0.014% ± 0.0003	0.0018 % + 0.0012

Table 3 - Exposure of applicators and operators as a percentage of the toxic dose (adapted from Adamis et al., 1985)

2.2.3. Other variations

Other variations influencing the exposure level may occur. For example, the plantation manager may decide to assemble teams of workers trained for handling pesticides. At the company level, the manager can organize training course on pesticides handling practices and health risks linked to pesticides, addressed to all the company’s workers. The manager can also decide to subcontract pesticide application to a service provider. In this case, the manager is relieved from providing instruments to protect operators (e.g. PPE buying and carrying out policies to encourage operators to wear them).

In case the manager wants to operate also on workers exposure (and not only on operators' one) he/she can prompt workers to exit from the plot when it is treated, or to treat when workers are not in the plantation (e.g. on Sunday, by night, etc.).

Another example is the literacy level. Indeed, when operators are illiterates, they are not able to read the security precautions which could be available on the pesticide cans. So, variation in literacy level can help to change the exposure level.

2.3. What are the current methods to assess farmworkers health?

The current methods specifically assessing farm workers health (workers exposed to one specific pesticide) are long and cumbersome. Some are cohort study, which compares the evolution of the health state of one group of affected people (workers submitted to pesticides) to the health state of one control group (non- exposed workers), along the time. The results are likelihood of getting ill if exposed, obtained by statistical means. In Wesseling et al. (1996) for instance: "A retrospective cohort study was carried out. Workers on the payrolls of banana companies, as reported to the Social Security System at any time between 1972 and 1979, were followed up in the cancer registry between 1981 and 1992: 29 565 men and 4892 women for 407 468 person-years. The observed cases of cancer were compared to the expected values, derived from the national incidence rates". Alavanja et al. (2013) study the increase of cancer burden among pesticide applicators, and among workers involved in the pesticide production. Other studies are monographies (using several reporting methods), bearing witness of specific workers illness, especially in case of scandalous negligence about their protection, e.g., exposures occurring during pregnancy (e.g., Bassil et al., 2007; Infante-Rivard and Weichenthal, 2007; Zahm and Ward, 1998). The negligence have consequences on children because of both prenatal exposure, and the parental exposure to pesticides at work (e.g., Van Maele-Fabry et al., 2010). Prenatal exposure can deal to pathologies (e.g., Mascarelli, 2013; Potera, 2014) or to fetal death (e.g., Wesseling et al., 2001). The monographies draw attention of general public on specific toxic substance, but can't be used to assess the effects of other pesticides than the ones disclosed. These methods provide pieces to assess impacts on workers' health, but they are too time-consuming to cope with our specification. Thus, we have to check methods dealing with assessing effects of pesticides on "human health" in general.

There are different current evaluation methods for the purpose of anticipating health state. A literature analysis highlights that methods contributing to the anticipation of impacts of pesticides on human health can be classified into two different groups: Environmental Life Cycle Assessment methods (E-LCA) and Risk Assessment methods (RA).

The Environmental Life Cycle Assessment (E-LCA) methods which match our topic are those including the environmental endpoint damage[15] category "Human Health" (HH) (Goedkoop and Spriensma, 2001). The principles of impacts on HH calculation is as following. There are some issues (e.g. toxicity for humans) which are deemed influencing the health of an "average human being", through different causal relationships.

For instance, assessing the toxicological effects of a chemical emitted into the environment implies a causal relationship called "pathway" (Figure 5) that links emissions to impacts through three steps: environmental fate, exposure, and effects (Huijbregts et al. 2010).

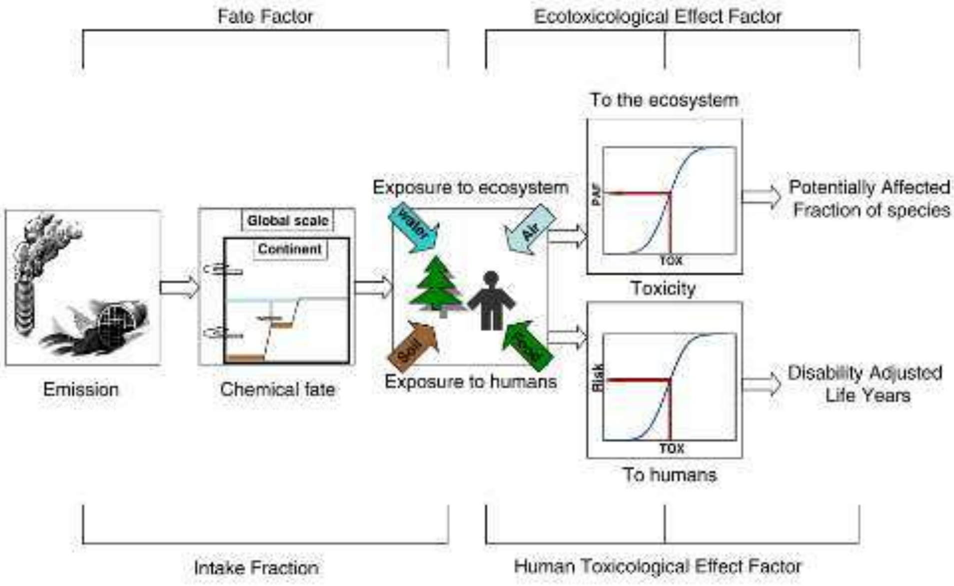

Figure 5 - Schematic representation of an E-LCA « pathway » between emission and impact on HH (from Van Zelm et al., 2009)

We will be back to E-LCA methods in the next paragraph (§ 2.4).

[15] It seems appropriate to differentiate the concepts of midpoint and endpoint. Midpoints are considered to be links in the cause-effect chain (environmental mechanism) of an impact category, prior to the endpoints, at which characterization factors or indicators can be derived to reflect the relative importance of emissions or extractions (Bare et al., 2000). At the endpoint level, most of these midpoint impact categories are multiplied by damage factors and aggregated into three endpoint categories: Human health, Ecosystems, and Resource surplus costs (Goedkoop et al., 2009b).

The Risk Assessment (RA) methods are used in regulation about toxic substances. The Guidance Document would be for use in regulatory risk assessment for plant protection products (PPP), both to determine eligibility for inclusion in Annex 1 of Council Directive 91/414/EEC4, and also to underpin the authorization of products by individual Member States. Currently, RA for operators, workers, bystanders and residents uses a deterministic method. This method checks if the reasonable upper estimates for daily systemic exposure are below a relevant toxicological reference value, called the Acceptable Operator Exposure level (AOEL). (EFSA, 2014). We will turn back to RA methods in the paragraph 2.5.

In the next two paragraphs (§ 2.4 and 2.5), our objective is mapping the range of the two groups of methods and analysing their strengths and weaknesses, referring to the following question: "Are these methods able to evaluate different ITK?" The two groups will be analysed regarding their capacity of distinguishing between different possible ITKs taking into account the impact on human health due to pesticides exposure.

2.4. Environmental Life Cycle Assessment and Human Health

In this paragraph, we will deepen the following issue: how impacts on Human Health are considered by the E-LCA methods? We will start from the scientific debate about how impacts on HH are treated in E-LCA methods (§ 2.4.1), then we will analyse the E-LCA methods currently in use to evaluate HH impacts (§ 2.4.2), and what are outputs of our test of E-LCA methods (§ 2.4.3). At the end, we will summarize advantages and drawbacks of E-LCA methods concerning our topics of interest (§ 2.4.4).

2.4.1. Scientific debates about the impact "Human Health" in E-LCA

The problem at hand is that it doesn't exist a consensual method able to assess impacts on Human Health, in the scientific community of E-LCA. Disagreement addresses modelling of emissions, calculation of toxicity and weighting.

In E-LCA methods, there is no collective agreement about the modelling of emissions from pesticides use. Especially the calculation of toxicity is challenging. "The harmonisation of methods and models to account for the potential environmental impact of products and organisation is at the core of many European and international initiatives. […] A key methodological aspect, not implemented yet in any of the above-mentioned initiatives, is the choice of models to estimate emissions from pesticide use. In fact, different approaches have been developed, but a common agreement in the scientific community has not been achieved yet." (Garavini et al. 2015, 45).

The ILCD Handbook, elaborated by the Joint Research Center (JRC)[16] of the European Commission since 2007, is the reference for European E-LCA methods. In the ILCD Handbook (2011), the JRC recommends using the USEtox[17] 1.0 IA method (Rosenbaum et al., 2008) to assess Human toxicity for cancer and non-cancer effects at midpoint level. The assessment is implemented trough the indicator "Comparative Toxic Unit for humans" (CTU_h). Even so, in the classification made by the Handbook[18], this method is classified as II/III types. This means that the toxicity impact categories have higher uncertainties than most of the others (e.g. Pant et al. 2004). This is reflected in the level II or III for some chemical groups (Galatola and Pant, 2014). At the endpoint level the same Handbook recommends assessing the impact category "Human toxicity, cancer effects" by the LCIA method of DALY calculation applied to USEtox 1.0 midpoint (adapted from Huijbregts et al., 2005a). Nevertheless, it is classified as "II/interim", so it is not considered as suitable to assess this type of impact, but it is nevertheless adopted in the absence of other valid methods. For the assessment of the impact category "Human toxicity, non-cancer effects" no methods are recommended.

The present doubts demonstrate that E-LCA methods cannot totally provide the required level of technical detail and prescriptiveness needed. Despite they can't ensure a consistent application of provisions that lead to robust, reproducible and comparable results, they provide a much needed and indispensable framework. To date, the European Commission is preparing

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16 The Commission's Joint Research Centre (JRC) implement the European Platform on LCA, Institute for Environment and Sustainability working closely with DG Environment, Directorate Green Economy. This Platform supports business and government needs for the availability, inter-operability, and quality of life cycle data and studies.

17 The USEtox™ model is an environmental model for characterization of human and ecotoxicological impacts in LCIA.

18 The recommended characterisation models and associated characterisation factors are classified according to their quality into three levels: "I" (recommended and satisfactory), level "II" (recommended but in need of some improvements) or level "III" (recommended, but to be applied with caution). A mixed classification sometimes is related to the application of the classified method to different types of substances. The classification "interim" indicates that a method was considered the best among the analysed methods for the impact category, but still immature to be recommended. (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

a consensual method (Product Environmental Footprint (PEF)) to implement E-LCA in the same way, everywhere in Europe. The urgency of the request and the need to include certain features in the new PEF methods obliged the Commission to carry out the work based on its own expertise and the inputs of experts gathered through consultations and pilot tests (Galatola and Pant, 2014).

While weighting is part of many - if not all- decision-making processes and part of the majority of current environmental policies, weighting is often hidden. For example, in the case of developing a carbon footprint standard, 100 % of the weight is implicitly and automatically assigned to climate issues (Galatola and Pant, 2014). So, the weighting of the diverse sources of impacts on human health are not consensual neither.

2.4.2. The E-LCA methods in use

2.4.2.1. Choice of the E-LCA method to test

In a first phase, we present the main used E-LCA Impact Assessment (IA) methodologies, which are useful to evaluate the environmental endpoint damage category "Human Health" (Goedkoop and Spriensma, 2001).

The general E-LCA models taken into account are the following:

- Eco-Indicator 99 (Goedkoop and Spriensma, 2001)
- CML 2002 (Guinée et al., 2002)
- EDIP 2003 (Hauschild and Potting, 2005) that is not an update of the older EDIP 97. They are complementary.
- ReCiPe 2008 (Goedkoop et al., 2009a) that represents an update of both Eco-Indicator 99 and CML 2002, and its update ReCiPe 2016 (Huijbregts et al., 2016).

All these models have been analysed to understand the general functioning and the methodological theories behind them. The focus is about the evaluation of the impacts of toxicity on HH. Following a chronological criterion, we decided to test ReCiPe 2016 about its capability to anticipate pesticides' impact on HH, because it gathers the best features of the older methods.

In the chapter “Toxicity” (referring to both ecotoxicity and human toxicity) of the handbook of ReCiPe 2016, the authors declared that this chapter is primarily based on the work by Van Zelm et al. (2009, 2013). Changes compared to the ReCiPe2008 chapter are:

- Separate midpoint factors for human cancer and non-cancer effects;
- Fate and exposure for dissociating organics included;
- USEtox organic and inorganic database implemented (3094 substances in total);
- Linear approach only for damage factor calculations.
- Effects on agricultural soil are excluded to prevent double counting with land use impact category.

The routes of exposure considered in the modelling of ReCiPe are: air, drinking water and food. We must notice that, on the contrary, and as explained above (§ 1.1.2), the main route of exposure for agricultural workers is the dermal one.

Due to the lack of other methodological information, we proceeded by analysing jointly ReCiPe 2008 (Goedkoop et al., 2009a) and its update 2016 (Huijbregts et al., 2016).

2.4.2.2. General presentation of the ReCiPe method

ReCiPe 2008 comprises two sets of impact categories with associated sets of characterisation factors. Eighteen impact categories are addressed at the midpoint level. Among them is human toxicity (HT). At the endpoint level, most of these midpoint impact categories are further converted and aggregated into three endpoint categories: damage to human health (HH), damage to ecosystem diversity (ED), and damage to resource availability (RA) (Figure 6).

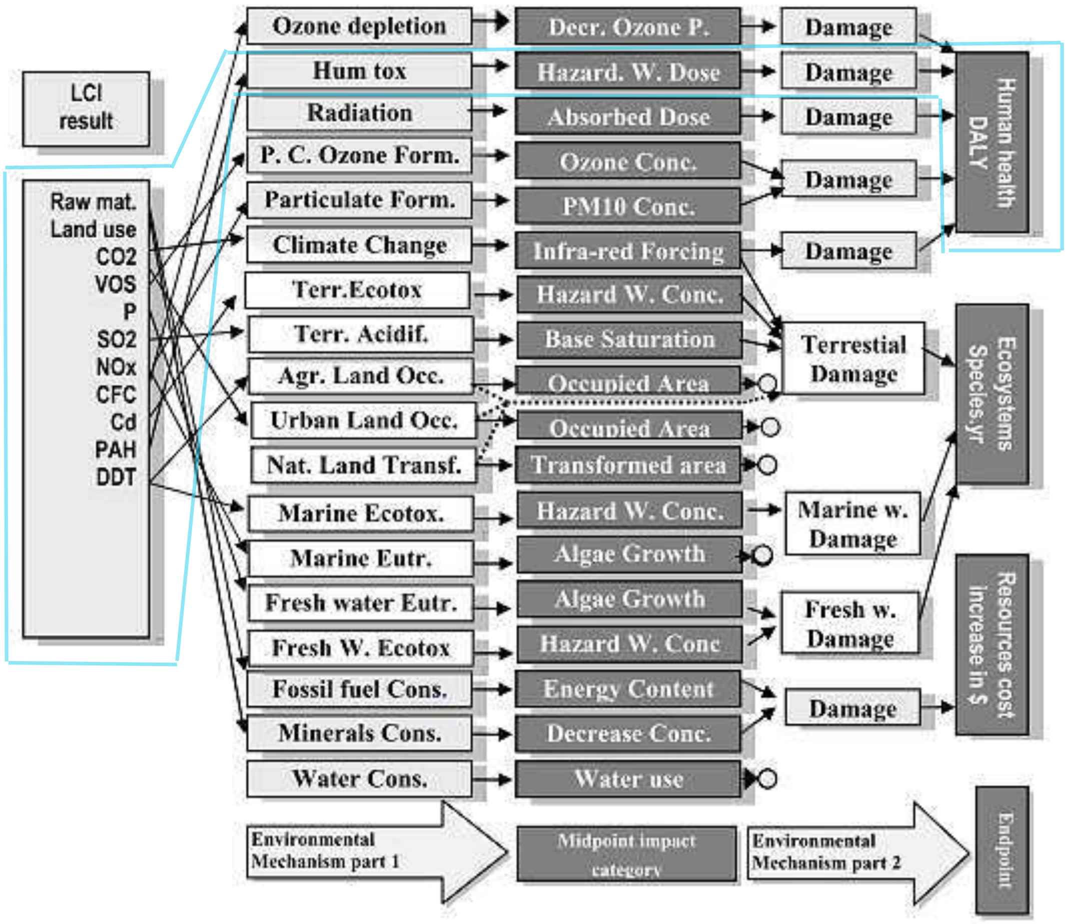

Figure 6 - Relationship between LCI parameters (left), midpoint indicator (middle) and endpoint indicator (right) in ReCiPe 2008 (adapted from Goedkoop et al., 2009)

At midpoint level, the impact category human toxicity (HT) is measured by the indicator "hazard-weighted dose", but contrary to all the other indicators, no unit of the physical or chemical phenomenon modelled is defined (Figure 7).

Impact category		Indicator	
Name	abbr.	name	unit*
climate change	CC	infra-red radiative forcing	W×yr/m^2
ozone depletion	OD	stratospheric ozone concentration	ppt†×yr
terrestrial acidification	TA	base saturation	yr×m^2
freshwater eutrophication	FE	phosphorus concentration	yr×kg/m^3
marine eutrophication	ME	nitrogen concentration	yr×kg/m^3
human toxicity	HT	hazard-weighted dose	–
photochemical oxidant formation	POF	Photochemical ozone concentration	kg
particulate matter formation	PMF	PM_{10} intake	kg
terrestrial ecotoxicity	TET	hazard-weighted concentration	m^2×yr
freshwater ecotoxicity	FET	hazard-weighted concentration	m^2×yr
marine ecotoxicity	MET	hazard-weighted concentration	m^2×yr
ionising radiation	IR	absorbed dose	man×Sv
agricultural land occupation	ALO	occupation	m^2×yr
urban land occupation	ULO	occupation	m^2×yr
natural land transformation	NLT	transformation	m^2
water depletion	WD	amount of water	m^3
mineral resource depletion	MRD	grade decrease	kg^{-1}
fossil resource depletion	FD	upper heating value	MJ

Figure 7 - Midpoint categories and indicators (adapted from Goedkoop et al. 2009)

The actual modelling of interventions into midpoint indicators is performed by the use of characterisation factors. For the midpoint impact category HT, the unit of the indicator result is the number of kg of 1,4-dichlorobenzene (1,4DCB) to urban air and the characterisation factor is "human toxicity potential" (HTP).

Endpoint characterisation factors (CFe) are directly derived from the midpoint characterisation factor (CFm) with a constant mid-to- endpoint-factor per impact category by

$$CFe_{x,c,a} = CFm_{x,c} \times F_{M\rightarrow,E,c,a}$$

Equation 1 - Endpoint charcterization factors structure in ReCiPe 2016

Where c denotes the cultural perspective, a denotes the area of protection (human health, terrestrial ecosystems, freshwater ecosystems, marine ecosystems or resource scarcity), x denotes the stressor of concern and $F_{M\rightarrow E,c,a}$ is the midpoint to endpoint conversion factor for cultural perspective c and area of protection a. These mid-to-endpoint factors are constant per impact category, because environmental mechanisms are considered to be identical for all stressors after the midpoint impact location on the cause-effect pathway. In case of cancer toxicity, the midpoint to endpoint factor is 3.3E-06 for the three cultural perspective. For non-cancer toxicity this conversion factor is 6.7E-09.

At the endpoint level, the impact category defined is "damage to human health" (HH). It is the disability-adjusted loss of life years (DALY) (unit: years).

2.4.2.3. *Characterization factor of human toxicity*

As shown in Figure 8, the characterization factor of human toxicity (for the pesticide I) accounts for the environmental persistence of I ($fate_I$), for the accumulation in the human food chain (exposure I), and for the effect (toxicity) of a chemical I. Fate and exposure must be combined into the "population intake fraction". It is a relative appraisal, whose reference is the intake and the toxicity of the chemical 1,4-dichlorobenzene (1,4-DCB) emitted to urban air.

In other terms, the characterization factor of human toxicity is the product obtained by multiplying the "population intake fraction" because of the exposure to the chemical x, by the "effect factor" caused by x on this population, the whole being related to the product obtained by multiplying the "intake fraction" of 1,4-DCB emitted to urban air, by the "effect" caused by 1,4-DCB to population.

Fate and exposure factors can be calculated by means of 'evaluative' multimedia fate and exposure models, while effect (toxicity) factors can be derived from toxicity data on human beings and laboratory animals. ReCiPe 2016 handbook declared to use the commonly applied multimedia fate, exposure and effects model: USES-LCA (Uniform System for the Evaluation of Substances adapted for LCA) 2.0[19] (Van Zelm et al., 2009).

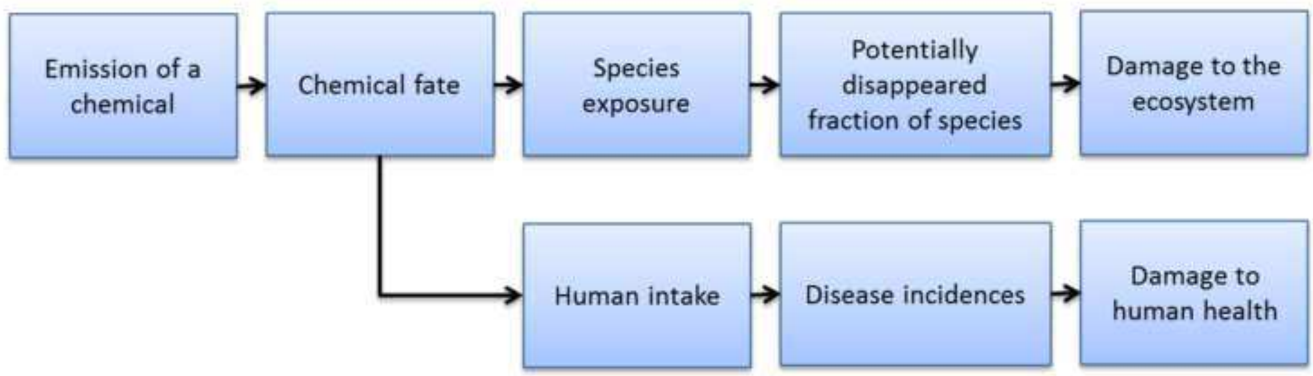

Figure 8 - Cause-and-effect chain from emissions to damage to the ecosystem and to damage to human health (from Huijbregts et al., 2016)

The calculations of the damages are done in two steps: at midpoint level, then at endpoint level.

2.4.2.4. *The fate and exposure factors at midpoint level*

[19] USES-LCA 2.0 calculates by default environmental fate and exposure factors in multiple compartments and human intake factors for inhalation and oral intake using an infinite time horizon.

At midpoint level, the toxicity potential[20] (TP) of one chemical is used as characterization factor for **human toxicity**. The chemical 1,4-dichlorobenzene (1,4-DCB) is used as a reference substance in the midpoint calculations, by dividing the calculated potential impact of the chemical by the potential impact of 1,4-DCB **emitted to urban air for human toxicity**. The TP depends on the fate and exposure factors.

The fate factor considered is (from ReCiPe 2008):

$$F_{j,i,x} = \frac{\partial C_{j,x}}{\partial M_{i,x}}$$

Equation 2 - Fate factor structure in ReCiPe 2008

in which:

-$F_{j,i,x}$ represents the compartment-specific fate factor that accounts for the transport efficiency of substance $_x$ from compartment $_i$ to and persistence in compartment $_j$ (year.m–3),

-$\delta C_{j,x}$ is the marginal change in the steady state dissolved concentration of substance $_x$ in compartment $_j$ (kg.m–3), and

-$\delta M_{i,x}$ is the marginal change in the emission of substance $_x$ to compartment $_i$ (kg.year–1).

USES-LCA 2.0 calculates compartment-specific fate factors for one freshwater, one sea, three oceanic and seven soil compartments. Emission compartments identified were urban air, rural air, freshwater, seawater, agricultural soil and industrial soil on the Western European scale.

Figure 9 shows the emission compartments, the environmental receptors and human intake routes identified in the fate factor calculations.

[20] The unit of the toxicity potential is kg of 1,4-dichlorobenzene-equivalents (1,4DCB-eq).

EMISSION COMPARTMENTS	ENVIRONMENTAL RECEPTORS	HUMAN EXPOSURE ROUTES
URBAN AIR	Terrestrial environment	Inhalation
RURAL AIR	Freshwater environment	Ingestion via root crops
FRESHWATER	Marine environment	Ingestion via leaf crops
SEA WATER		Ingestion via meat products
AGRICULTURAL SOIL		Ingestion via dairy products
INDUSTRIAL SOIL		Ingestion via eggs
NATURAL SOIL		Ingestion via freshwater fish
		Ingestion via marine fish
		Ingestion via drinking water

Figure 9 - Emission compartments, environments and human exposure routes included in ReCiPe 2008 (from Goedkoop et al., 2009)

The **exposure factor** is the route-specific intake fraction for the human population, and is called $iF_{r,I,x,g}$. This represents the human population intake fraction at geographical scale *g* that accounts for transport of substance *x* via intake route *r* from emission compartment *i* (dimensionless).

2.4.2.5. The human toxicological characterization factor at endpoint level

In ReCiPe 2016, "the human toxicological midpoint characterization factor consists of an intake fraction (iF), a combined effect and damage factor (EF) and the characterization factor for 1,4-dichlorobenzene". This midpoint characterization factor (= toxicity potential) is specific of the compartment in which the substance has been emitted, of the intake route (oral or inhalation), of the scale (continental, moderate, tropic, arctic), and of the effect (carcinogenic, non-carcinogenic). All these toxicity potentials are aggregated to an overall human population characterization factor of substance x emitted to compartment i, as depicted by the Equation 3:

$$HTP_{i,x/k} = \sum_{r} \sum_{g} \frac{iF_{x,i,r,g} \times EF_{x,r/k}}{iF_{DCB,ua,r,g} \times EF_{DCB,r/k}}$$

Equation 3 - *Human population characterization factor in ReCiPe 2016*

- $HTP_{i,x/k}$ represents the human characterization factor at midpoint level for effects of substances x to emission compartment i (kg 1,4DCB to urban air eq./kg).
- $iF_{x,i,r,g}$ is the human population intake fraction of substance x at geographical scale g via intake route r emitted to compartment i
- $EF_{x,r/k}$ is the effect factor of substance x for intake route r, reflecting the change in life time disease incidence due to a change in intake of the substance and intake route of interest. They work with a linear dose–response function for each disease endpoint and intake route. For substances that lack relevant effect data on the exposure route of interest, route-to-route extrapolation with help of allometric scaling factors, and oral and inhalatory absorption factors was performed (EC, 2004). In case chemical-specific information on absorption factors was lacking, complete oral and inhalatory absorption was assumed.

In the text, there is an example of midpoint characterisation factors (CFs) (1,4-DCB eq/kg) for 1,4-DCB and Nickel, but no indications are provided on how to calculate CFs for other substances. For human health damage calculation, we multiply the amount of the substance x emitted by the relevant "Human characterization Factor", as calculated above.

No clear indication is provided about how to calculate the different parts of the Equation 3. In this way, it is hard to use the tool without any IA software making calculation for the practitioner.

For human health damage, carcinogenic and non-carcinogenic endpoint characterisation factors (CFhum) are calculated (Equation 4):

$$CF_{hum_{x,i/k}} = HTP_{x,i/k} \times F_{M \rightarrow E,HTOX,k}$$

Equation 4 - Carcinogenic and non-carcinogenic endpoint characterisation factors in ReCiPe 2016

where $HTP_{x,i/k}$ is the human toxicity potential for carcinogenic or non-carcinogenic effects of substance x to emission compartment i (in 1,4DCB-eq/kg) and $F_{M \rightarrow E,HTOX,k}$ is the midpoint to endpoint factor for human carcinogenic or non-carcinogenic toxicity (k).

In the specific field of toxicity there are various IA methods useful to evaluate impacts, some of these are specific for pesticide impacts. These specific methods are USEtox 1.0 and 2.0 (Rosenbaum et al., 2008) and PestLCI 2.0 (Dijkman et al., 2012). Both of them are not considered in this analysis because they are not relevant for the topic under scrutiny. PestLCI 2.0 does not address impacts on HH. The EC-JRC (2011) considered USEtox 1.0 as “invalid for direct applications of pesticides (and metal) on crops with regard to the impact on human health” (Basset-Mens 2015), and USEtox 2.0 isn’t different regarding that point[21].

Moreover, there is a scientific debate on DALY validity as indicator for damage to HH. The possibility of translation of the equation results in DALY will be deepen in paragraph 7.4.

2.4.3. Test of E-LCA methods regarding differentiation of ITKs

As explained before, we need to know the capability of current E-LCA methods to make a distinction between different ITKs. We display the results by following the classification designed in paragraph 2.2.

Variations in Product ITK: referring on how it is demonstrated by Garavini et al. (2015), most of currently used pesticides are not included in the databases requested by LCA tools (e.g. Ecoinvent). Consequently, the practitioner is often obliged to set many hypotheses to “replace” the real pesticide by another which is documented in the database. In this way, the theoretical constructed model may differ completely from the reality of the analyzed case study. When the pesticides are included in the database, E-LCA calculations accounts for the change from one pesticide to the other.

Variations in Applying ITK: E-LCA methods are able to gather only quantitative variations of the used product. They can assess a variation of ITK only if the change of application technique leads to a variation of product quantities and input/output ones used in the analyzed process. Frequently, if one changes the application technique, also the product changes (because of the tendency of chemicals firms to sell jointly the pesticide with application instruments perfectly suitable with it). When the product changes, we go back to the problems raised by the “ITK product”, above. E-LCA methods, moreover, don’t take into account HH impacts due to a different way or magnitude of exposure to the pesticide.

[21] In the documentation of USEtox 2.0 (Fantke et al., 2017) reported that “The human exposure model of USEtox 1.01 was documented and published in Rosenbaum et al. (2011) and has not been modified in USEtox 2.0 (except for the addition of an indoor exposure model and exposure to crop residues, but these additions do not affect the general exposure model)”.

Variations in Cultivation ITK: In general, if one changes the cultivation method, it will change also the productivity of the system. E-LCA methods are capable to assess this variation through the reference flow. We set the example where one passes from a cultivation system that had a productivity of 1 ton of bananas per hectare (ha) to another cultivation system with productivity of 2 tons/ha. If we set our functional unit (FU) equal to the service rendered by 1 ton of bananas, the subsequent reference flow is 1ha for the old cultivation system, and 0.5 ha for the new one. The variation of the cultivation system frequently entails a variation of pesticides application techniques (e.g. if the plants density increases, it might not be possible to use tractors or quads for the application, but only instruments carried back by workers). This, as already specified above, can lead to a product variation also. In this way, we go back to problems highlighted for "product ITK" and "applying ITK".

Moreover, as it is specified in the ISO 14040/44 2006, E-LCA aims to assess the potential impacts generated by the product to the environment without focusing on a stakeholder group (e.g., agricultural workers).

We are considering the case of pesticide emission in a plantation. Following midpoint E-LCA modelling, in this case the emission compartment will be "Rural air". The environmental receptor, in this case, will be "Freshwater environment", and the Human exposure route "Ingestion via root crops". So, no reference is done to the dermal exposure, typical of operators work through air.

Recalling the general research question (§ 1.3.4.3), it emerges that ReCiPe 2008/2016 is not adapted to answer. In fact, no plantation managers could be in measure to manage this type of tool. Plantation managers are usually low educated people and not confident with the use of IT technologies. E-LCIA methods are developed by engineers and loaded in LCA software (e.g., SimaPro, OpenLCA). IA methods are a "black box" for the practitioner.

It is useful to highlight that this method appears as unsuitable to take into account operator exposure to pesticides in banana plantations. First, all the compartments are identified on the Western European scale and not for tropical environment, where chemical fate can be different from temperate regions. Second, human exposure to chemicals is considered here as indirect exposure through one of the compartments, despite the main exposure for agricultural worker is direct contact.

2.4.4. Summary of advantages and drawbacks of E-LCA methods

We sum-up below the main advantages and drawbacks of ELCA methods regarding our purpose, which is assessing the effects of pesticides on farm workers' health for different types of change in ITK.

Advantages of E-LCA methods:

- They calculate human health, whose legitimacy as a relevant social impact is not challenged.
- When there are no toxic substances in the value-chain (e.g. no pesticides), different E-LCA methods provide quite similar ranking of the scenarios to be assessed.

Drawbacks of E-LCA methods:

- There is little consensus on the calculation of the impact HH in E-LCA. Especially the calculation of toxicity is challenging. The USEtox 1.0 and 2.0 methods tried to build a consensus but didn't get it yet.
- These methods have a limited validity for all regions that cannot be defined as well-developed temperate regions (Goedkoop et al. 2009, 5). Indeed the methods are developed in Europe for the Europe itself, inasmuch they use European normalisation values (Goedkoop and Spriensma, 2001; Guinée et al., 2002; Hauschild and Potting, 2005).
- In the E-LCA method, the main way of exposure is inhalation, while the field exposure studies have shown that in the workplace, the main route of exposure is the dermal one (Adamis et al., 1985; Inserm (dir.), 2013).
- Except for "indoor exposure" (Hellweg et al., 2009) the methods address HH at level of one average human being, and not at the level of targeted populations.

For all these reasons, we can't use E-LCA methods to address the anticipation of agricultural workers heath because of pesticides use, linked with changes in ITKs.

2.5.Risk Assessment methods and human health

In this phase of the thesis project, one proceeds to analyse the RA methodology. We will study the models used in the agricultural sector that assess the HH impact, while paying special attention to the methodologies that focus on pesticides.

The methodologies taken into account are:

- IDEA (Zahm et al., 2004);
- EIQ (Kovach et al., 1992);
- A method developed by the Danish Environmental Protection Agency, Ministry of Environment and Energy (OCDE 2001);
- A method developed by the Swedish National Chemical Inspection Office (OCDE 2001);
- IRPeQ (Samuel et al., 2012) and its adaptation to Europe (Mghirbi et al., 2015).

Despite the revision work on the different assessment models is not complete yet, it is already possible to make the following observations.

A distinction is made between acute and chronic toxicity. But there are not always concerns about how to evaluate them differently, given their radically different nature.

The assessment criteria for chronic toxicity considered in the models are, in general: carcinogenicity, genotoxicity, endocrinal perturbation, reproduction, development.

For acute toxicity, the assessment criteria are: DL_{50} oral (mg/kg), DL_{50} dermal (mg/kg), CL_{50} inhalation (mg/l), dermal irritation, ocular irritation, sensitization. For each ones of these criteria a numerical value is assigned and, then, the different values are combined in a mathematical formula whose result is a number: the value of the impact.

From a general analysis of the models found till today, emerges the idea that the exposure regarded as having the most harmful effect is the inhalation one, despite in the field of pesticides, the worst way of exposure is the contact.

We can test the RA methods for their capability to differentiate the changes in different ITKs cited in paragraph 2.2. To do so, we take the example of the equation (Equation 5) developed by Mghirbi et al. (2015) to assess the Health Risk Indicator for Operators (*Indicateur de Risque Santé Applicateur*, IRSA).

$$\boldsymbol{IRSA\ active\ substance = IRTas \times FPf \times FCP \times FPa}$$

Equation 5 – Health Risk Indicator for Operators

$$IRSAproduct = \sum IRSAas$$

$$Toxicity\ Risk\ Indicator\ (IRTas) = [acute\ toxicity + (chronic\ toxicity \times persistence\ factor)]^2$$

$$FPf = weighting\ factor\ on\ formulation\ of\ commercial\ product$$

$$FCP = weighting\ factor\ on\ dose\ applied$$

$$FPa = adjustment\ factor\ on\ application\ technique$$

We can test the capability of this formula to accounts for the different levels of change in ITKs.

- Product ITK. If the product applied changes, all parts of the equation will change.
- Applying ITK. If the application technique changes, consequently it will change also the adjustment factor FPa (which can take the values 1, 1.5 or 2), and the dose applied (that takes the value for FCP). If it changes also the product (which is frequently the case) we are in the case of "product ITK" above.
- Cultivation ITK. Caused by the variation of the cultivation system, we can assume a variation of application techniques and products also. We are therefore in the cases previously analysed.

Theoretically, this equation is capable to assess the variations between two different products. In fact, the problem with this type of equation is its construction which can be criticized from different points of view. "IRSA active substance" value is proportional to ALL the term of the equation. So, to all terms of the equation is given the same importance.

1. It must be highlighted that the chronic toxicity assessment is more difficult and inaccurate than the acute toxicity assessment. There may be an underestimation of the chronic toxicity to the detriment of acute toxicity (if you are not aware of the disease/risk, you do not care/there is no prevention).

2. Regarding “FPf” it is not clear how to calculate it. It is based on Samuel et al. (2012). At page 5 of the report there is a table (Table 4) where is exposed that the more severe exposure is the inhalation one, despite in the field of pesticides the worst way of exposure is contact.

3. As we noticed sooner, the application technique is really important. It seems insufficient to take it into account through an adjustment factor (FPa) only. By changing consideration of the application technique, it would change the model of evaluation of impacts, and then the entire equation.

More in general, Equation 5 amplifies the error to calculate the different members (see point 1 and 2 here above).

In general, we can say that the model was created to demonstrate that toxicity is the more important factor to evaluate HH. *Vice versa*, in the field of pesticides, the exposure is the major subject to investigate (and consequently the application technique).

In sum, the current method of risk assessment is not completely satisfactory. For some exposure scenarios, the empirical data underpinning exposure estimates are sparse, making the estimates less reliable. For others exposure scenarios, several models may be available, displaying inconsistency between the approaches. This can be the case also for models adopted by regulatory authorities. Furthermore, exposure values based on 50th or 75th centiles of empirical datasets may substantially underestimate the maximum exposures that could reasonably occur in a single day, compromising margins of safety for PPPs which are acutely toxic (EFSA, 2014).

2.6. Conclusion

The two groups of methods (E-LCA and RA) were explored about their capability to answer the research question. For differing reasons, they do not fit in our specifications (§ 2.1). We therefore need to develop our own method. The literature review underpins that present methods are more or less able to handle the issue of changes in “product ITK”, or will be able to do so, when data basis will be more documented. Unfortunately, emerges a lack for assessing what we call “applying ITK” and “cultivation ITK”. No one present method is able to fairly assess both kinds of changes. The cause is the deep gap in scientific knowledge regarding effects of application of pesticides, and effects of changes in cultivation systems, upon human health.

Chapter 3: The Research Design

From the literature reviews emerges a gap regarding real practices assessment. In those rare cases when the real practices are assessed, the study is too context related about a single substance (e.g., Feola and Binder, 2010). It is therefore impossible to generalize the results. For these reasons, our contribution is to develop a method sensitive to changes in product ITK, application ITK and cultivation ITK, while assessing real practices of operators.

As we need to concretely solicit experts, it is mandatory to shrink the field where we will collect expert experience. For the reasons exposed in paragraph 3.1, we choose banana crop. We therefore present the research design (§ 3.2).

3.1. Why to deepen the case of banana plantation?

3.1.1. Importance of banana market

Banana is one of the world's most important crops grown by small- and large-scale producers alike, with production occurring in more than 130 countries. The economic importance of the banana industry encompasses (1) the generation of export earnings and (2) the employment of hundreds of thousands of people in Latin America, the Caribbean, Southeast Asia, and West Africa. In addition, the industry employs thousands of people in distribution networks and supermarkets worldwide (Evans and Ballen, 2012).

In 2009, world production of bananas reached an estimated 97.3 million metric tonnes (mmt), grown on 4.9 million hectares. The 2009 crop represented an increase in production of 49 percent from the 65.1 mmt recorded in 2000.

As reported by Loeillet (2017), World production of bananas is currently in the order of 134 million tonnes (62 million tons of Cavendish and 72 million tons of other banana types), but covers a very wide variety of varieties and uses. Dessert-type banana production accounts for 59% of world production.

The current leading banana-exporters countries are presented in Table 4.

Europe	Surface in production (ha)	Export (tons)
Canary	9 100	364 000
Cyprus	200	4 000
Guadeloupe	2 700	74 000
Greece	100	2 000
Martinique	7 600	192 500
Madeira	1 030	19 000
Africa		
Côte d'Ivoire	7 300	305 000
Cameroon	7 800	284 000
Ghana	1 700	51 000
Caribbean		
Dominican Republic	20 145	342 000
Windward Islands[22]	3 500	8 000
Central America		
Mexico	11 914	417 000
Costa Rica	43 000	1 800 000
Honduras	19 000	676 000
Guatemala	33 000	2 100 000
Belize	2 800	105 000
Panama	5 000	275 000
Nicaragua	2 000	70 000
South America		
Brazil	500	18 000
Colombia	50 250	1 700 000
Ecuador	162 000	5 800 000
Peru	6 500	189 000
Suriname	2 800	59 000
Asia		
Philippines	85 000	2 600 000

Table 4 - Leading exporters worldwide (adapted from Loeillet, 2017)

[22] Grenada, Saint Lucia, Saint Vincent and the Grenadines, Dominica.

3.1.2. *Quantities of pesticides employed*

Traditional agricultural production in developing countries is coming under growing pressure from globalization and market forces, with the result that intensive agriculture is increasingly being seen to play a major role in their rural economies, as already reported by London et al. in 2002. In this way the use of potentially hazardous chemicals is encouraged. These are used to combat pests and boost the production but represent also a significant risk to HH.

While many developed countries have begun pesticides-reduction programs, in developing countries sales of pesticides have increased significantly. This phenomenon is particularly developed in countries in economic and political transition dominated by agricultural economies. Generally, these economies practice intensive agriculture, in order to increase potential foreign revenue from agricultural exports, crucial to national development strategies.

As reported by London et al. (2002), evidence for the link between economic policy and expanded pesticide usage is widespread in the developing world. For example, agriculture in Central and Latin America, particularly the production of ornamental plants, tropical fruits and vegetables, relies on chemical inputs, with an increase of pesticide usage from the 1990s. In fact, in these places are farmed cotton and bananas (traditionally quoted as extremely pesticide-dependent) and non-traditional export crops, in which a higher pesticide usage was recognized.

From the institution point pf view, policies to promote intensive use of pesticide has been extended to small producers and households, moreover, there are also cases of institutionalized culture that favors pesticide use has arisen, for example, in Costa Rica and South Africa.

3.1.3. *Difference between prescribed and real practices*

In order to minimize exposure and, consequently, health risk (in particular during the application phase), is suggested the use of specific Personal Protective Equipment (PPE) (e.g., Inserm (dir.), 2013; International Labour Organisation, 1991; World Health Organization, 1990). Often, smallholders in developing countries fail to comply with these safety standards. In fact, as reported by Feola and Binder (2010) an inadequate use of PPE has been reported and investigated, for instance, in Asia (e.g., Atreya, 2007; Dung and Dung, 2003; Palis et al., 2006; Snelder et al., 2008), the Middle East (e.g., Gomes et al., 1999), Africa (e.g., Matthews et al., 2003; Mekonnen and Agonafir, 2002; Ngowi et al., 2007; Ntow et al., 2006) and Latin America (Celina Recena et al., 2006; Jørs et al., 2006; Polidoro et al., 2008; Waichman et al., 2007).

As reported by Feola and Binder (2010), this non-protective behaviour may be correlated to various aspects, such as:

- Education (Mekonnen and Agonafir, 2002; Salameh et al., 2004)
- High cost of PPEs (Yassin et al., 2002)
- Contingent and/or external factors. E.g., language and graphic conventions used in designing labels which are present on pesticide packages were not understood by local users (Gomes et al., 1999; Waichman et al., 2007); farmers consider PPE uncomfortable to be worn during work in the field (Cole et al., 2002)
- Values and cultural orientation, that influence risk perception and, consequently, adequate safety practices adoption (e.g., Palis et al., 2006)
- Social norms. "There may be a social norm implicitly defined according to the most widely accepted behavior in the region (such as *not* using PPE) which leads farmers to conform in order to avoid a symbolic sanction (such as mockery)" (Feola and Binder, 2010).
- Other aspects (e.g., age, previous experience of adverse pesticide-related health effects

Given the variety of behavioral drivers which potentially influence farmers' PPE use, knowing which ones are relevant in a specific context is essential to develop effective intervention strategies against PPE misuse. In effect, any intervention's effectiveness depends on the ability of specifically targeting different combinations of drivers. In this respect, the potential influence of social norms on farmers' PPE use is a critical issue.

3.2.Research design

The research design starts from the tested research question (§ 3.2.1) to explain the theories in use (§ 3.2.2). We therefore sum up the whole research design (§ 3.2.3).

3.2.1. Tested research question

The carried out literature review demonstrated that it is necessary to build a new method able to discriminate between different production systems, in terms of the impact on operators' health, based on real practices.

To do this, our research must answer the following three research questions:

- How is it possible to collect fair information about real practices implemented in the plantation?
- How is it possible to represent the collected information?

- How is it possible to develop an indicator taking into account plantation' real practices?

3.2.2. Theories in use

Research methods can be classified in numerous ways, however one of the most common distinctions is between qualitative and quantitative research methods. Quantitative research methods were originally developed in the natural sciences to study natural phenomena. Qualitative ones were first developed in the social sciences to enable researchers to study social and cultural phenomena. This work can be ascribed in this latter category.

All the researches (whether quantitative or qualitative) are based on some underlying assumptions about what constitutes 'valid' research and which research methods are appropriate. In order to conduct and/or evaluate qualitative research, it is therefore important to identify these (sometimes hidden) assumptions. Epistemology[23] refers to the assumptions about knowledge and how it can be obtained (Hirschheim, 1992).

To justify the validity of knowledge, each research must be part of an epistemological paradigm. An epistemological paradigm is a "conception of knowledge shared by a community, based on a coherent system of foundational hypotheses relating to the issues studied by epistemology" (Gavard-Perret, 2012:23).

In the human and social sciences, there are several classifications of contemporary epistemological paradigms, corresponding to different currents of thought. Chua (1986), and Orlikowski and Baroudi (1991) suggest three categories, based on the underlying research epistemology: positivist, interpretive and critical.

Positivists generally assume that reality is objectively given and can be described by measurable properties which are independent of the observer (researcher) and his or her instruments. Positivist studies generally attempt to test theory, in an attempt to increase the predictive understanding of phenomena.

Otherwise, critical researchers assume that social reality is historically constituted and that it is produced and reproduced by people. Although people can consciously act to change their social

[23] The concept of epistemology appeared in the twentieth century to designate a branch of philosophy specializing in the study of theories of knowledge. Today it is considered "the study of the constitution of valid knowledge" (Piaget, 1967: 6). It is concerned with three problems: what is knowledge? How is it elaborated? How to justify the validity of knowledge? These questions are essential to reflect on the relevance and validity of the knowledge development process implemented in relation to the objective pursued, scilicet, the research methodology chosen by the researcher.

and economic circumstances, critical researchers recognize that their ability to do so is constrained by various forms of social, cultural and political domination. Critical research focuses on the oppositions, conflicts and contradictions in contemporary society, and seeks to be emancipatory i.e. it should help to eliminate the causes of alienation and domination.
Interpretive researchers start out with the assumption that access to reality (given or socially constructed) is only through social constructions such as language, consciousness and shared meanings (Myers, 1997). For example, interpretivism states that social reality is first and foremost constructed by actors, who construct the meaning of reality by sharing their representations. The reality is therefore subjective and constructed in the social practices of actions and interpretations. These interpretations can be the object of consensus within a social group, such as in the approach to the social construction of reality (Berger and Luckman, 1966). Interpretive studies generally attempt to understand phenomena through the meanings that people assign to them and interpretive methods of research aim at producing an understanding of the context of the information system, and the process whereby the information system influences and is influenced by the context. The knowledge generated is essentially descriptive. Following Popper, being interpretivist requires to making a precise analysis of the knowledge and information available to the actors in a given situation, that is, a work of understanding. This fine analysis should highlight the ex-ante and ex-post actors' knowledge, with their evolution during the period, and the observer constructs his interpretation of the events considering also ex-ante and ex-post perspective (Dumez, 2006).

This thesis is part of an interpretive approach, because we account for the interpretation of actors. We know that when managers or workers report that operators and workers always wear PPE, they have their own reasons to declare it, independently of factual practices. It is known that experts may be wrong, but, according to Surowiecki (2004) and his "Wisdom of Crowds" theory, which affirms that by aggregating a large number of imperfect estimates, the group could make a much better estimate than the most skilled individuals. For this reason, we have elicited several experts in the field of banana plantations real practices. The experts elicited are from different disciplines implicated in plantation management (e.g. primarily agronomy and management sciences). As highlighted above, the gap in knowledge is wide and deep. Managers must take decision in a context where "system uncertainties[24] or decisions stakes (or both) are

[24] The term "system uncertainties" means that the problem is not the discovery of one fact, but the comprehension or management of a reality.

high." (Funtowicz and Ravetz, 1994, page 1884). We face "unpredictability, incomplete control, and plurality of legitimate perspectives." (Funtowicz and Ravetz, 1994, page 1881). In such a context, a resort is claiming for expert elicitation. Indeed, the idea is that the expert's experiences encompass (and can stand for) all the complex system of relationships embedded in the issue. We try to replace incomplete science by expert's experiences.

Education might not always be the most appropriate intervention policy to target PPE misuse. Instead, more articulated intervention strategies may be needed to promote safer pesticide use among smallholders in developing countries

3.2.3. Design of the whole research

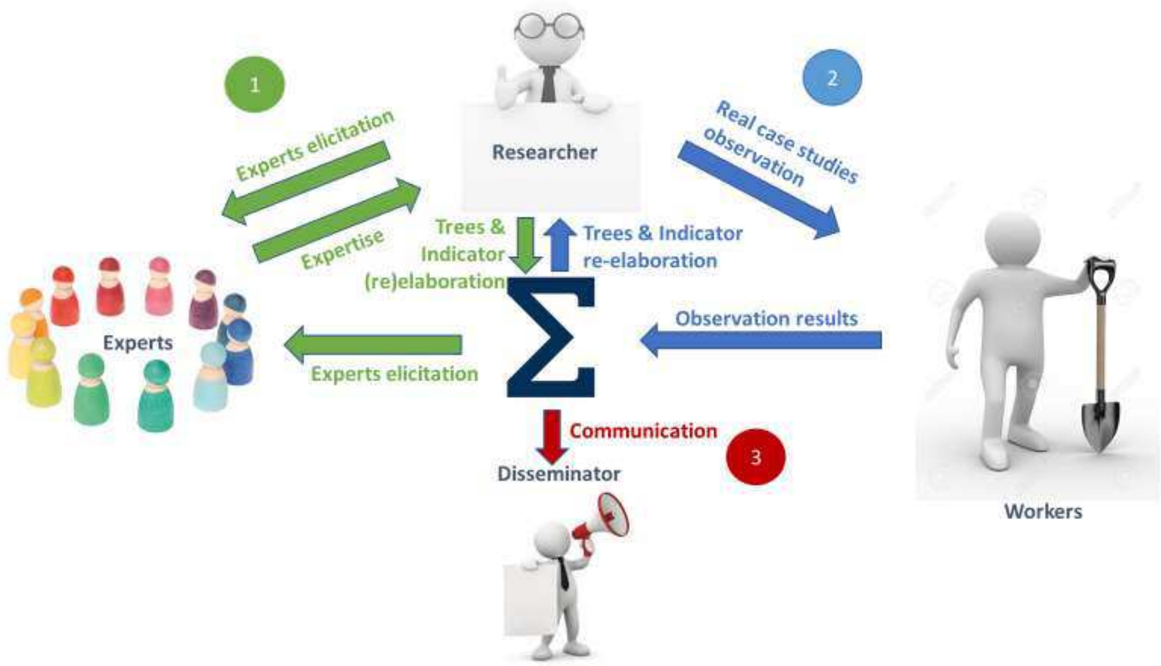

Figure 10 - Design of the whole research

On the base of the literature review, since the current methods (E-LCA and RA) don't allow considering the actual practices, we propose a model that takes into account practices and is usable in order to anticipate future impacts.

We will base our work on the expertise (Figure 10), which affirms how under some particular working conditions (e.g., heat and humidity) the exposure risk becomes very strong, e.g. for the misuse of personal protective equipment (PPE). We will elicit experts on this topic through a Delphi Expert Consensus Method (Jorm, 2015).

After that we will represent this information through knowledge trees. Then, we will proceed in testing our trees through the observation of a real case study. With the information collected both from experts and from the case study, we will be able to devise an indicator, usable by plantation managers to evaluate the implemented production systems and the consequences of eventual changes (e.g., in type of product used, plantation practices, work management).

Chapter 4: Research Method: the expert elicitation

To build a method assessing the human impact of pesticides for operators, we followed the following steps: selection of experts and to gather their expertise (§ 4.4.1, 4.4.2, 4.4.3); development of knowledge trees (§ 4.4.4); development of decision trees (§ 4.4.5); calculation of the human impact of pesticides for operators according to a given farming system (§ 4.4.6).

In this section, we explain why we chose the Delphi method, and specifically the Delphi expert consensus method, and how we proceeded to gather the information.

4.1.Expert systems in agriculture

In any agricultural production system, accumulation and integration of related knowledge and information from many diverse sources play important role. Agriculture specialists and raw experiences are the common sources to provide information that the different stakeholders require for decision making to improve agricultural production.

In recent years, tools, technologies and applications of information technologies have emerged as efficient and effective measures for upgradation of the whole agricultural fields, ranging from scientific studies to farmers help. Integration of expert system as a powerful tool for the stakeholders of agricultural production has extensive potential (Sarma et al., 2010).

The applications of expert systems (ES) are rapidly increasing. Such applications are very affective in situations when the domain expert is not readily available. In agriculture, applications of expert system are mainly found in the area of diseases diagnosis and pest controls (Sarma et al., 2010).

In the agricultural sector ES has been implemented as rule-based ES using ESTA[25] (Prasad et al., 2006), and by Khan et al. (2008), where the system is for the purpose of pest and disease control of Pakistani wheat. They had developed the system with web-based expert system using e2gLite™ shell available freely on the internet.

[25] The Expert System Shell for Text Animation (ESTA), is an expert system developed by Prolog Development Center (PDC), Denmark and used by the authors for the diagnosis of the most common diseases occurring in Indian mango.

Chopra et al. (2000) explain that "it is ... possible to develop a consensus model of expertise through an iterative process of individual elicitation on a set of elements, assembly of the results and re-elicitation on the new set of elements" (Léger and Naud, 2009).

When expert consensus is based purely on personal experience, we are in the case that can be called "practice-based evidence".

4.1.1. Choosing Delphi expert consensus method

The consensus changes over time as knowledge increases. For this reason, it is advisable to associate a consensus and a Delphi method. The Delphi method is one of many that have been used to build expert consensus[26]. Sometimes consensus builds rapidly and spontaneously in science, based on a critical piece of evidence.

This is more often the case in epidemiological and medical sciences, where a single piece of evidence may be sufficient to change expert beliefs (Jorm, 2015). The quality of the evidence they produce depends on the inputs available to the experts (e.g., systematic reviews, experiments, qualitative studies, personal experience) and on the methods used to ascertain consensus.

The validity of the approach is supported by the theory of "wisdom of crowds" (Surowiecki 2004) showing that groups can make good judgements under certain conditions.

The Delphi technique was described by one of its originators as "a method of eliciting and refining group judgments" (Dalkey 1969). It was originally developed as a method for forecasting, but has since been widely applied in other areas, including health research. The Delphi method has many variants, but the key elements are as follows:

1. There is a facilitator who organizes the Delphi study.

2. The facilitator recruits a group of individuals with some expertise on the topic.

3. The facilitator compiles a questionnaire with a list of statements that the experts rate for agreement.

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[26] A Delphi expert consensus method is defined as "a systematic way of determining expert consensus that is useful for answering questions that are not amenable to experimental and epidemiological methods" (Jorm, 2015).

4. The facilitator gathers responses from the members of the group using the questionnaire.

5. The facilitator gives anonymous feedback to individuals in the group about how their responses compare to the rest of the group.

6. The members of the group are able to revise their responses to the questionnaire after receiving the feedback.

7. Responses converge across rounds of questionnaires, with some statistical criterion being used to define consensus.

In the field of the estimation of burden and disease costs an example of use of the Delphi experts consensus method was implemented by Trasande et al. (2015), where it was used to judge the strength of epidemiological data in "[E]stimating Burden and Disease Costs of Exposure to Endocrine-Disrupting Chemicals in the European Union".

For expert consensus to produce good answers, it needs to be ascertained systematically and using methods that are known to produce accurate outcomes. There has been research on the conditions under which groups of individuals with some expertise make good decisions. James Surowiecki (2004) has summarized this literature in his book "The Wisdom of Crowds", where the term 'crowd' is used to refer to any collection of individuals with some expertise, including scientists. Surowiecki proposes that certain conditions must be met for a crowd to be wise:

1. Diversity of expertise. A heterogeneous crowd of experts will produce better quality decisions than a homogeneous one.

2. Independence. The experts must be able to make their decisions independently, so that they are not influenced by others.

3. Decentralization. Expertise is held by autonomous individuals working in a decentralized way.

4. Aggregation. There is a mechanism for coordinating and aggregating the crowd's expertise.

In parallel four key features may be regarded as necessary for defining a procedure as a 'Delphi' (Rowe and Wright, 1999). These are:

1. Anonymity. It is achieved through the use of questionnaire. this should allow the individual group members to consider each idea on the basis of merit alone;

2. Iteration, With the iteration of the questionnaire over a number of rounds, the individuals are given the opportunity to change their opinions and judgments without fear of losing face in the eyes of the (anonymous) others in the group.

3. Controlled feedback. Between each questionnaire iteration it is provided through which the group members are informed of the opinions of their anonymous colleagues.

4. Statistical aggregation of group response. At the end of the polling of participants (i.e., after several rounds of questionnaire iteration), the group judgment is taken as the statistical average (mean/median) of the panelists' estimates on the final round. The final judgment may thus be seen as an equal weighting of the members of a stabilized group.

4.1.2. Knowledge elicitation in the banana case

In a first phase, the expert pool was selected choosing people that experienced directly the real practices implemented in banana plantations. The pool was composed by: agronomists, economists and exposure assessments experts.

In compliance with the above-mentioned requirements, most of the elicitation process is carried out through individual interviews of about 1 hour. Agronomists were interviewed in group sessions.

Following the requirements of Surowiecki (2004):

1. The wisdom-of-crowds literature clearly shows that crowds make better decisions when they include diverse expertise (Jorm, 2015). Selecting the expert panel, the researcher has to choose a group of individuals who have expertise relevant to the question. Ideally, there should be a clear definition of what constitutes expertise and a sampling strategy for locating experts who meet it.

   Experts from different scientific areas were selected: 2 agronomists, 3 economists and 1 exposure assessment specialist.

The type of experts to be included depends on the question being asked. We chose this expertise in function of our need of mapping real practices implemented in banana plantations both from the agronomic point of view both from the exposure one, giving importance also to the work organization in the plantation. In addition of the experts elicited, a computer scientist specialist in expert knowledge elicitation in the agricultural sector was interviewed regarding the information organization.

2. All the experts were interviewed separately and anonymously.

3. All the experts interviewed are employed in independent organization working on agricultural and environmental practices improvement.

4. The information collected from the expertise was organized in 9 knowledge trees (Huosong et al. 2003; Yager 2006; Marceau 2007).

A round consisted of interviews of each expert. A synthesis is done to close the round after everyone was interviewed once. Rounds were and will be repeated until more interviews do not improve the knowledge and the consensus level is high enough.

The agronomists were interviewed to collect knowledge on each phase of banana farming systems implemented in the various part of the World. The aim was to map the different existing "banana workflows" and the causes of bad practices occurring during the workflow. The gathered knowledge allows us to indicate, for each elementary action, what is the level of exposure to pesticides for the operators. Economists were interviewed regarding their competence on work management, and the exposure assessment specialist regarding the quantity and quality of the exposure due to the practices cited by the agronomists.

Beyond the Delphi method implemented a computer scientist was consulted regarding the construction of the workflow diagram and to acquire knowledge regarding the informatics implementation.

The knowledge collected though the interviews was organized in knowledge charts.

4.1.3. Devising knowledge trees

We organized the charts in a chronological way: first the different steps that compose a banana production system were identified. For each one the sub-steps to be implemented were

highlighted. Only for operators, we identified the alternative action modalities to accomplish each sub-step, between which the choice can be made. At last each action implies that three tasks (where exposure to pesticides can occur) take place: the preparation, application and instrument cleaning ones.
Only the operator population was considered.

During the first round an initial version of the knowledge trees were drawn. The changes proposed by the expert during a subsequent interview may be an addition, a deletion or a modification of several chart elements.

At this moment, the different possible banana production systems have been split into the nine phases of banana cultivation for the duration of one plantation. So, nine knowledge trees were built corresponding to the main phases of banana cultivation:

1. Destruction of the old plantation
2. Fallowing
3. Nursery
4. Nursery (shadehouse)
5. Fertilization
6. Weeding
7. Plant protection (Black Sigatoka and weevils)
8. Bunch care
9. Post-harvest treatments (in the packaging plant)

We structured the charts in order to map the different alternatives regarding the three main occasions of exposure for operators: preparation of the pesticide mixture, pesticide application and equipment cleaning (included the treatment of the residues of the pesticide mixture).

Chart structure

A workflow[27] can be represented as a chronological sequence of steps, sub-steps, actions and tasks (Figure 11).

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[27]A workflow can be defined as "[A]n orchestrated and repeatable pattern of business activity enabled by the systematic organization of resources into processes that transform materials, provide services, or process information" (IBM 2016).

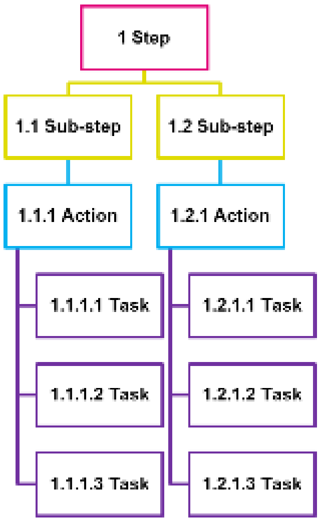

Figure 11 - Workflow representation

We organized the charts in a chronological way: first the different steps that compose a banana production system were identified. For each one the sub-steps to be implemented were highlighted. Then we identified the alternative operating actions to accomplish each sub-step, between which the choice can be made. At least, each action implies that three tasks (where exposure to pesticides can occur) take place: preparation, application and instrument cleaning.

From literature, factors affecting the level of exposure include type of activity (e.g. application, mixing, loading or harvesting), method of application (e.g. air blast, backpack, aerial spray, hand spray or ground boom application), pesticide formulation (e.g., dilute spray, aerosol or dust), application rate (e.g., weight of active- ingredient/ha), use of PPE (e.g., gloves, respirators, face-shields, boots or overalls), and personal work habits and hygiene (e.g. changing into clean clothes/washing hands or taking bath/shower after the use of pesticide, frequency of healthcare visits) (Dosemeci et al., 2002). The real practices regarding all these factors are taken into account by the experts, when they deem that such or such task is performed with such a level of exposure.

Moreover, the interviews by experts highlight what are the relevant criteria which allow us to design the different branches of the knowledge tree. The relevant criteria initiating bifurcation between different branches are: methods of application and "PPE policies". Indeed, in the flowcharts was included the presence (or not) of "PPE policies". We call "PPE policies" the initiative that the plantation manager implements to encourage operators to wear PPEs. Usually they are trainings about the pesticide risk and about wearing PPEs or bonus payments (normally wage-depending). From the interviews emerged the idea that the implementation of these policies influences the operator exposure during the application task.

The knowledge trees devised are contained in Annex 7.

These knowledge trees have enabled us to draw decision trees (Annex 8).

4.1.4. Devising decision trees

While knowledge charts contain information about operations that can meet on the same field (e.g. fungicide treatment and weevil/nematodes treatment during the "plant protection" phase), decision trees contain only exclusive branches one of each other (e.g., the fungicide treatment can be conducted by air treatment OR by backpack sprayer).
The objective pursued by drawing decision trees is to organise the information necessary to calculate the human impact of pesticides (see § 4.4), but above all to prepare the computer implementation of knowledge collected from experts.

The structure in 9 steps, sub-steps, and actions is the same as for the knowledge charts.

In decision trees on operators, the three tasks (preparation, application and instrument cleaning) are also figured. These "operators" trees show the successive operations performed by an "average operator" of the plantation.

Each leaf of the decision tree provides information on the level of exposure of operators judged by experts, based on practices related to pesticides (good or bad) for such specific treatment alternative of the production system.

4.1.5. Pesticide human impact indicator

In this paragraph, we point out the indicator resulting from the knowledge trees.

A given production system may be represented by a combination of all or part of the various steps weighted by the number of times a treatment is carried out. For example, an annual banana cropping system can be represented by the following sequence:

4 treatments in step 5, then one treatment in step 6, then 40 treatments in step 7, then one treatment in step 8 and another in step 9.

We hypothesize that we can approach the pesticide human impact on the average operator by adding the pesticide human impacts of the tasks in which he/she is invested.

The pesticide human impact of a task for the average operator is proportional to the number of operators carrying out the task, the number of occurrence of the task, the degree of exposure of the average operator and the toxicity. The data needed to calculate the human impact of a pesticide task are:

- the number of operators carrying out the task;

- the number of occurrence of the task, which depends on the number of repetition of the pesticide treatment concerned. We consider that every action induces the three tasks "preparation, application, cleaning", but they could not concern the same number of operators, and will be calculated separately;

- the degree of exposure of the average operator indicated by the experts, for this part of the production system and this treatment modality. It is stated in the decision tree;

- to realize the toxicity of the product, we suggest using the inverse (1/AOEL) of the Acceptable Operator Exposure Level (expressed as mg of product per kg of body weight per day) of the product concerned.

The indicator that accounts for the implementation of an action consists of three related tasks (preparation, application, cleaning) can be written (Equation 6):

$$Human\ cost_{operators} \text{for one action} = \left(\sum_{j=1}^{3} N_{o_j} N_{t_j} X_j \frac{1}{AOEL_j} \right)$$

Equation 6 - "Human impact" indicator

with:

- j which means one of three tasks: preparation, application or cleaning

- N_{o_j} represents the number of operators involved in this task

- N_{t_j} denotes the number of times that the task is repeated, under the same conditions, on the perimeter of the space-time computation.

- X_j reflects the degree of operator exposure It was found out in the knowledge trees based on a specific task at a specific point of the production system.

- $AOEL_j$ identifies the AOEL of the product used in the task j.

The calculation of pesticide human impact can be achieved following several temporal and spatial aggregations:

- for the entire lifespan of a plantation (5-30 years)
- for the cycle corresponding to a single crop (9 months to 12 months in routine start)
- for all transactions for a year on a routine plantation (about 52 crops per year)
- by parcel, per hectare, or any area of the plantation

Interpretation of the results of pesticide human impact calculations should be done only by comparing two or more production systems between the calculations made to the same temporal and spatial scales. Indeed, the result of a calculation is meaningless in the absolute.

Chapter 5: Results

In this chapter, we will present an example of knowledge chart devised to map banana production systems (§ 5) and we develop an example of human impact indicator calculation (§ 5.2).

5.1.Knowledge charts example

In Figure 12 is reported an example of representation of one part of the banana production system by one knowledge tree. The step analyzed is the plant protection one. Two treatments (fungicide and nematicide one) have to be implemented in it. These two different treatments are here defined as "sub-step". Each sub-step can be accomplished through different alternative activities (e.g. aerial, mechanical or manual fungicide application). Each action has to be implemented carrying out three tasks: preparation (P), application (A) and instruments cleaning (C).

At the end of each task a label reporting the related exposure level (from the experts' opinion) was added. The exposure level was classified into: high, medium, low and no exposure.

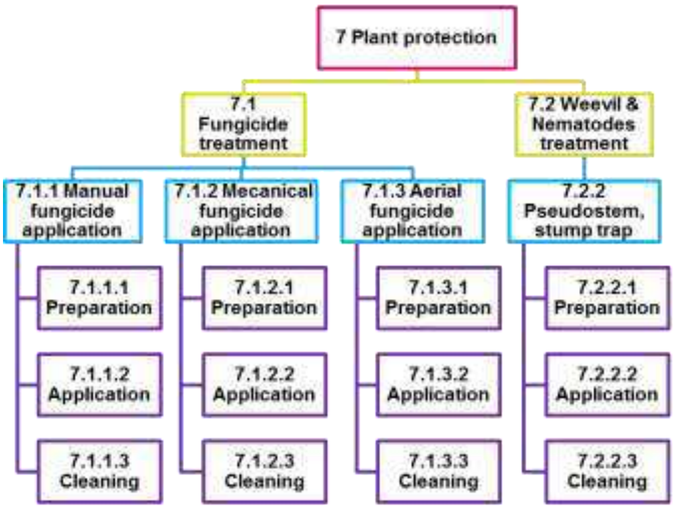

Figure 12 - Example of workflow representation

5.2. From charts to indicator for operators

The flowcharts (knowledge trees) built are useful to trace the entire banana production system step by step and decision by decision. The evaluation of the human impact of pesticides for operators may be done by comparison between different production systems, and thanks to the indicator presented at § 4.4.3. Here is an example displaying how we switched from knowledge trees to indicator.

<u>Example</u>

Hypothesis:

- We have a production system composed by three step:

  1 Destruction of the old plantation;

  3 Weaning;

  7 Plant protection.

- We work per total number of farm plots, per year.

- Due to the last two points in this example the comparison will be made only on the Application task for operators.

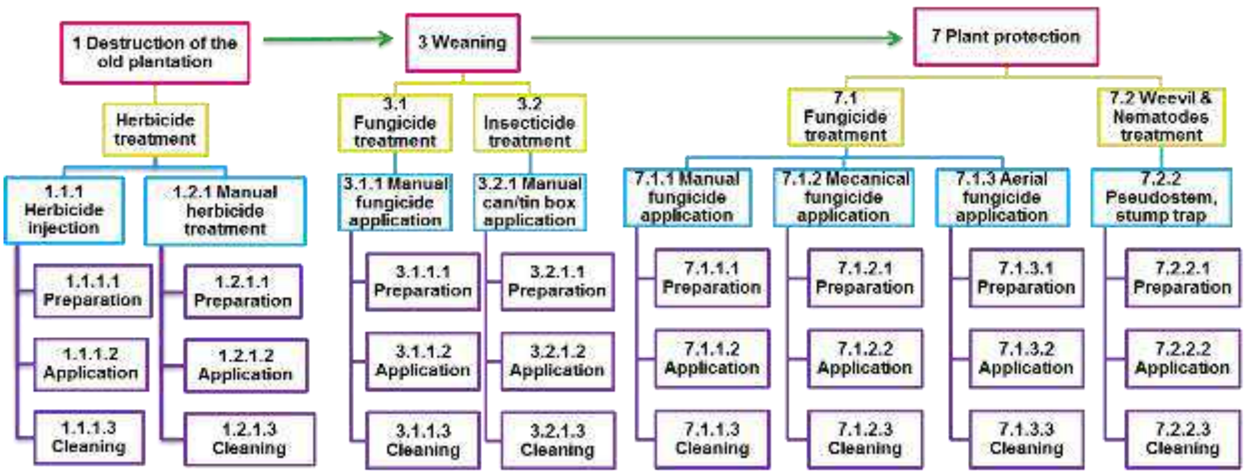

Figure 13 - Example of a simplified banana production system

We want to make the comparison between two different production systems per total number of farm plots and per year: A and B.

In the production system B we introduce:

- training about pesticide risk and PPE wearing

- herbicide injection (instead of backpack sprayer) in the "destruction of the old plantation" step.

Making also hypothesis regarding the number of treatments per year, the two different production systems can be represented as follows:

- Production system A:

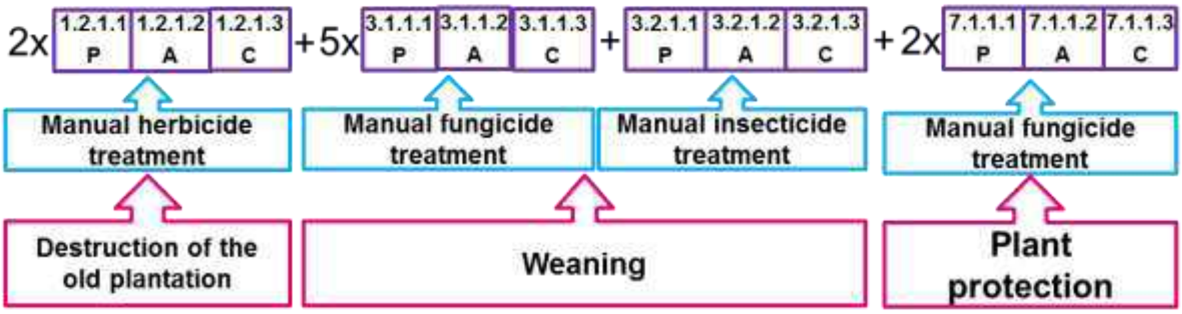

Figure 14 – Representation of the production system A

- Production system B:

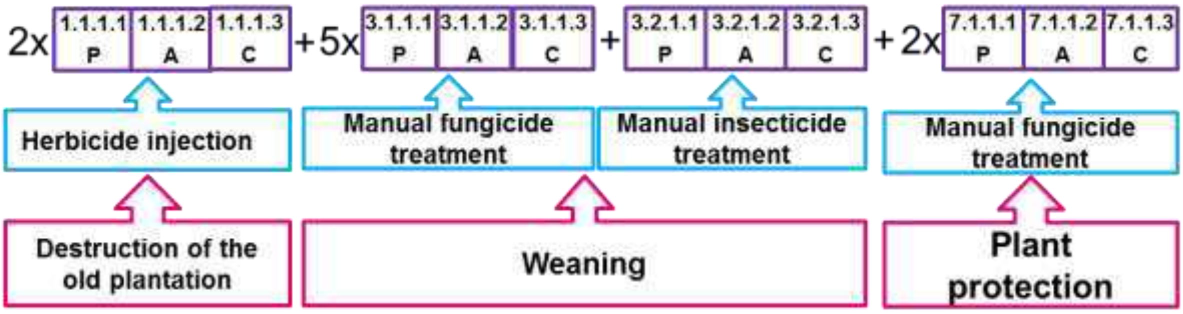

Figure 15 – Representation of the production system B

To each task of the production system, we are capable to associate an exposure level (from the knowledge charts) classified as follows. To simplify interpretation, we associate a colorimetric code to each level.

Figure 16 - Colorimetric code associated to different exposure levels

So, the exposure levels for the production system A are:

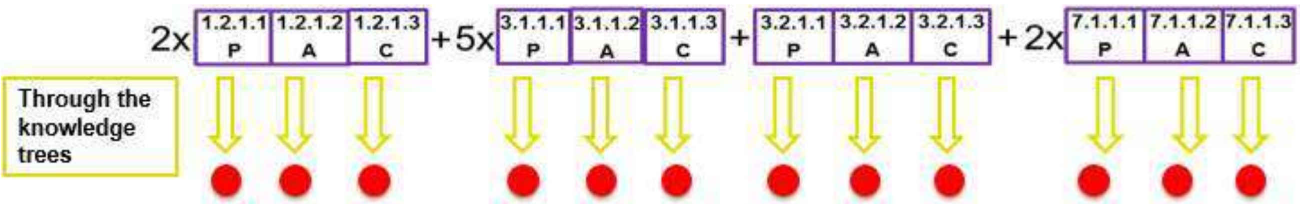

Figure 17 – Exposure levels associated to production system A

While for the B one is:

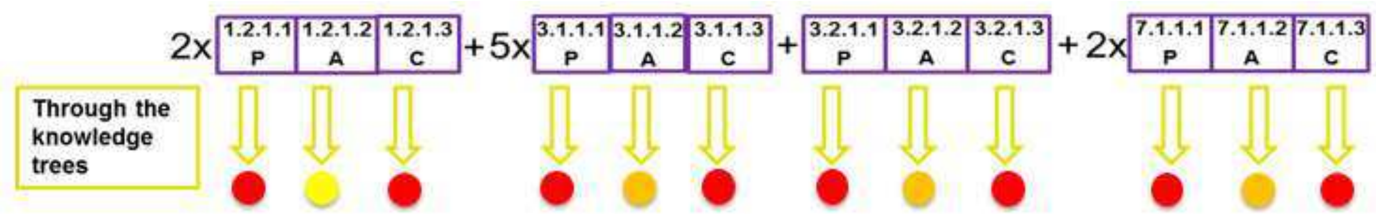

Figure 18 - Exposure levels associated to production system B

As reported in Figure 14 we associate different weighting factors (X_j) for different exposure levels:

$X_j = 1$ for "high exposure"

$X_j = \frac{1}{10}$ for "medium exposure"

$X_j = \frac{1}{100}$ for "low exposure"

In a subsequent phase, making hypothesis regarding:

- The number of operators affected for each task. In the reported example the number of persons affected both in the preparation and application task is the same, but not always this condition is verified, e.g. in the mechanical fungicide application, there may be 1 operators for the pesticide mix preparation, but more than 1 tractor/truck driver.

- The product used in each action. To each product is associated an Acceptable Operator Exposure Level (AOEL). This index represents the mg of active substance of which each operator is acceptable be exposed each day, in function of his body weight ($\frac{mg_{as}}{kg_{bw} \times day}$).

In the case examined, the pesticide human impact is:

$$Human\ cost_{operators} \text{for one action} = \left(\sum_{j=1}^{3} N_{o_j} N_{t_j} X_j \frac{1}{AOEL_j} \right)$$

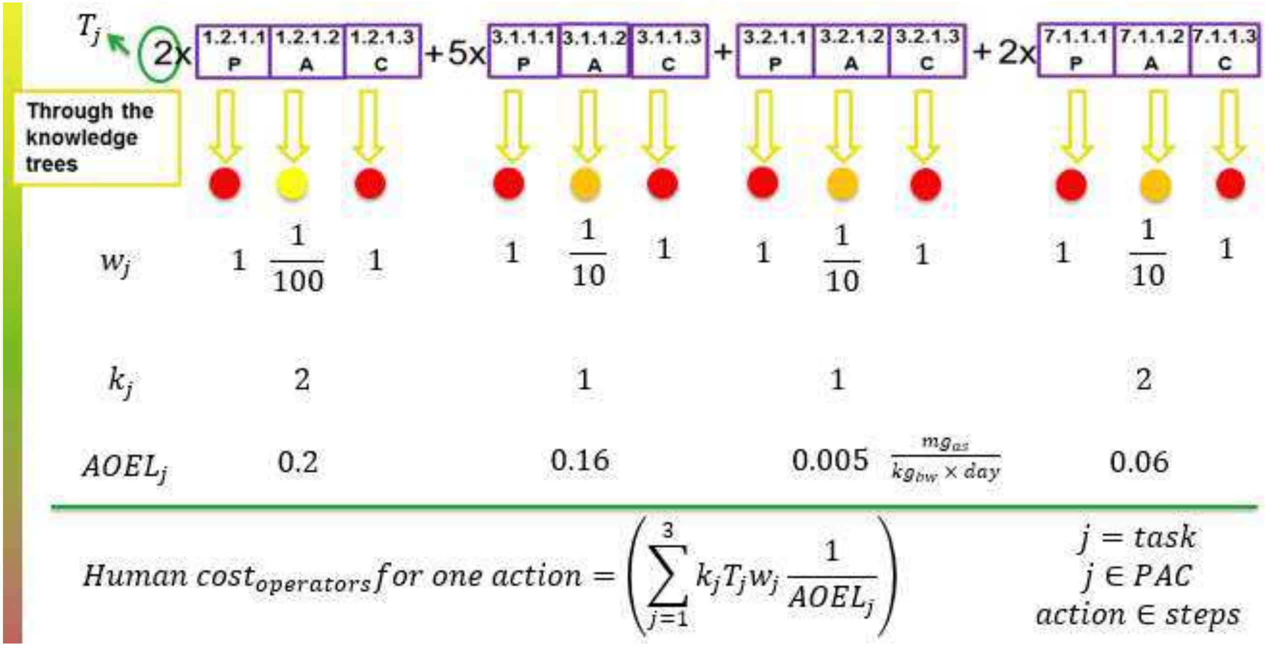

Figure 19 - Data to calculate the "human impact" indicator associated to production system B

- <u>Destruction of the old plantation</u>
  - Production system A:

$$Product: glyphosate, AOEL_{glyphosate} = 0.2$$

$$N_{o_j} = 2$$

$$N_{t_j} = 2$$

$$X_{j,A} = 1$$

$$Human\ cost_{o,A1} = \left(2 \times 2 \times 1 \times \frac{1}{0.2}\right) + \left(2 \times 2 \times 1 \times \frac{1}{0.2}\right) + \left(2 \times 2 \times 1 \times \frac{1}{0.2}\right)$$
$$= 20 + 20 + 20 = \mathbf{60}$$

  - Production system B:

$$X_{j,B} = \frac{1}{100}$$

$$Human\ cost_{o,B1} = \left(2 \times 2 \times 1 \times \frac{1}{0.2}\right) + \left(2 \times 2 \times \frac{1}{100} \times \frac{1}{0.2}\right) + \left(2 \times 2 \times 1 \times \frac{1}{0.2}\right)$$
$$= 20 + 0.2 + 20 = \mathbf{40.2}$$

- Nursery (work indoor)
  - Fungicide application: Production system A

$$Product: Difenoconazole, AOEL_{difenoconazole} = 0.16$$

$$N_{o_j} = 1$$

$$N_{t_j} = 5$$

$$X_{j,A} = 1$$

$$Human\ cost_{o,A2f} = \left(1 \times 5 \times 1 \times \frac{1}{0.16}\right) + \left(1 \times 5 \times 1 \times \frac{1}{0.16}\right) + \left(1 \times 5 \times 1 \times \frac{1}{0.16}\right)$$
$$= 3 \times 31.25 = 93.75$$

  - Insecticide application: Production system A:

$$Product: Fosthiazate, AOEL_{fosthiazate} = 0.005$$

$$N_{o_j} = 1$$

$$N_{t_j} = 1\ (admitted)$$

$$X_{j,A} = 1$$

$$Human\ cost_{o,A2i} = \left(1 \times 1 \times 1 \times \frac{1}{0.005}\right) + \left(1 \times 1 \times 1 \times \frac{1}{0.005}\right) + \left(1 \times 1 \times 1 \times \frac{1}{0.005}\right)$$
$$= 200 + 200 + 200 = 600$$

$$Human\ cost_{o,A2} = 93.75 + 600 = \mathbf{693.75}$$

  - Fungicide application: Production system B:

$$Product: Difenoconazole, AOEL_{difenoconazole} = 0.16$$

$$N_{o_j} = 1$$

$$N_{t_j} = 5$$

$$X_{1,B} = 1$$

$$X_{2,B} = 0.1$$

$$X_{3,B} = 1$$

$$Human\ cost_{o,B2f} = \left(1 \times 5 \times 1 \times \frac{1}{0.16}\right) + \left(1 \times 5 \times \frac{1}{10} \times \frac{1}{0.16}\right) + \left(1 \times 5 \times 1 \times \frac{1}{0.16}\right)$$
$$= 31.25 + 3.125 + 31.25 = 65.625$$

- Insecticide application: Production system B:

$$Product: Fosthiazate, AOEL_{fosthiazate} = 0.005$$

$$N_{o_j} = 1$$

$$N_{t_j} = 1\ (admitted)$$

$$X_{1,B} = 1$$

$$X_{2,B} = \frac{1}{10}$$

$$X_{3,B} = 1$$

$$Human\ cost_{o,B2i} = \left(1 \times 1 \times 1 \times \frac{1}{0.005}\right) + \left(1 \times 1 \times \frac{1}{10} \times \frac{1}{0.005}\right) + \left(1 \times 1 \times 1 \times \frac{1}{0.005}\right)$$
$$= 200 + 20 + 200 = 420$$

$$Human\ cost_{o,B2} = 65.625 + 420 = \mathbf{485.6}$$

- <u>Plant protection</u>
  - Production system A:

$$Product: Trifloxystrobine, AOEL_{Trifloxystrobine} = 0.06$$

$$N_{o_j} = 2$$

$$N_{t_j} = 2\ (admitted)$$

$$X_{j,A} = 1$$

$$Human\ cost_{o,A3} = \left(2 \times 2 \times 1 \times \frac{1}{0.06}\right) + \left(2 \times 2 \times 1 \times \frac{1}{0.06}\right) + \left(2 \times 2 \times 1 \times \frac{1}{0.06}\right)$$
$$= 66.67 + 66.67 + 66.67 = \mathbf{200}$$

- Production system B:

$$X_{1,B} = 1$$

$$X_{2,B} = \frac{1}{10}$$

$$X_{3,B} = 1$$

$$Human\ cost_{o,B3} = \left(2 \times 2 \times 1 \times \frac{1}{0.06}\right) + \left(2 \times 2 \times \frac{1}{10} \times \frac{1}{0.06}\right) + \left(2 \times 2 \times 1 \times \frac{1}{0.06}\right)$$
$$= 66.67 + 6.67 + 66.67 = \mathbf{140}$$

To calculate the total pesticide human impact of the entire production system:

$$Human\ cost_{operators} \text{for one year} = \sum_{actions} \left(\sum_{j=1}^{3} N_{o_j} N_{t_j} X_j \frac{1}{AOEL_j} \right)$$

$$Human\ cost_{\ A} = 60 + 693.75 + 200 = 953.75$$

$$Human\ cost_{\ B} = 40.2 + 485.6 + 140 = 665.8$$

5.3. Conclusions

Data collected so far must be simply gathered from real production systems or estimated for ex-ante use. This represents a strength of the method. In particular, the method requires no knowledge of the actual land applied doses, because it is an almost impossible given to know in banana systems. Moreover, due to variations in exposure magnitude and duration, routes of absorption (skin, respiratory tract, gastrointestinal tract), and physiological variability between exposed individuals, it is often difficult to quantitatively assess the effective dose of a pesticide an individual has received either by measuring working hours or by monitoring the contamination level of the workplace (Ye et al., 2013). The allocation of the different wj values by experts to the various tasks precisely fills in this gap.

Nevertheless, the proposed tool has several limits.

It doesn't account for health issue for agricultural workers who are not operators. Moreover, only preparation and application tasks are involved in the knowledge trees, because the experts have explained that they didn't have the opportunity to experience this step (so, they are not able to evaluate the corresponding wj of the task). In this context, our indicator is more suitable for some application methods than other. For example, if we consider the same fungicide treatment carried out by plane or by manual application with backpack sprayer, we are not able to provide a complete evaluation of this sub-step: in the aerial application, we have one operator (the pilot) and, potentially, many agricultural workers exposed if they not exit from the plantation treated. In the manual application, we have some operators applying the fungicide, and the same number of agricultural workers potentially exposed. Our indicator may not respect the proportion of the difference on operators between these two ways of implementation, because of the lack of an indicator for workers.

It takes into account only one production system, which is dessert banana for exportation. In fact, the elicitation work with expert must be done again for each new crop.

It is not implemented under software format yet. The software format would allow performing simulations. It would be therefore helpful to conceive new cropping systems.

About the different usages of the tool, we underpin that it is possible to calculate the human impacts on an existing production system, or about an upcoming production system. Data sources used in both cases will be different, as shown in the following table (Table 5). It is therefore possible to use charts and indicators to test several possible farming systems before implementing them. In this sense, this work contributes to innovation in farming systems.

Finally, the calculation can be done for different temporal and spatial system boundaries.

VARIABLES	$\sum_{actions}$	N_{o_j}	N_{t_j}	$X_{j,A}$	$AOEL_j$
CASE:					
FARMING SYSTEM IMPLEMENTED AND RECORDED DATA	All actions are known	Real number of operators for each task	Real number of repetition for each task	Taken from knowledge charts	All products are known, so AOEL noted
ANTICIPATION USE OR UNKNOWN DATA	Estimation of probable actions	Mean or probable interval	Observed mean or probable interval	Taken from knowledge charts	Average AOEL of the product category (4 categories)

Table 5 - Data sources and possible usages of the tool

Chapter 6: Feasibility test

This chapter intend to shed more light on the feasibility of the showed method, including how it will be accomplished.

6.1.Goal

The test aims to check difficulties that practitioner may face while trying to evaluate his/her own agricultural system. To do so we apply the method mentioned above. As outlined in § 1.4, we devise a method simple to implement, that can be successfully adopted by plantation managers, and used with simple data leading to a quick implementation.

In detail, the feasibility test aims at:

- identifying the given production system in a real case, among the production systems depicted by the knowledge trees. The test answers the following question: can we quickly and easily identify a given real production system from the combination of knowledge charts?

  This identification allows us to consult the w_j of each of the implemented tasks.

- checking whether the other data necessary for calculating costs are easy or not to collect on the plantation.
- checking if we can easily find alternative, for improving the production system or for helping to design new production systems.

After getting and interpreting results of the "human impact" indicator calculation in the feasibility test, we ought to propose improvements of the method.

6.2.Context of the case study in Dominican Republic

The paragraph presents the case study context, including historical background (§ 6.2.1), local roles of the banana export activity (§ 6.2.2) and features of the production systems (§ 6.2.3),

6.2.1. Historical background

In 1896, the first foreign company to produce bananas commercially set up operations in Dominican Republic, and left a few years later, despite having made substantial investments. It was not until 1943, that the Grenada Company established operations and started to export bananas from Manzanillo Port. In 1951, the Dominican Fruit Company established itself in Azua, where it operated until 1966. Subsequently, a period of instability affected the export of this crop. Nevertheless, by the 1990s, once the Port of Manzanillo was renovated, the country positioned itself as a leading exporter of this product, particularly to Europe.

Although bananas are cultivated in all regions of the country, the northern region accounts for 60% of production, specifically in the provinces of Valverde, Santiago Rodriguez, Montecristi and Dajabon. The Southern region follows with 12% of the harvest and the Central region produces 11% (FAO, 2017). There is no established season for planting bananas, but producers prefer cultivation in the months of June and August because it is the cycle when the plant's requirements are more favourably satisfied regarding temperature, rainfall and light.

Banana production has increased significantly in the country, especially in the last years, when it went from 18.2 million bunches in 2008 to 24.1 million in 2009, followed by 30 million in 2010, to 35.5 million in 2012, which represents a growth rate greater than 80%. In 2012, approximately 22,757 hectares were harvested with bananas, with a production of approximately 34 million bunches of banana valued at RD$ 4,675 million. This production mostly supplies the export market due to the growing volume of organic banana exports, which represent close to 80% of all organic exports of the country.

6.2.2. Banana export and its contribution to the national economy

The Dominican Republic is the largest producer of organic bananas worldwide, representing more than 55% of the World's organic banana production. Despite being a relatively small player in the global banana market, the Dominican Republic stands out as its most important source of organic bananas, and is therefore a useful demonstration of common implementation methods, their results, and the challenges faced by producers wishing to change to organic methods. A special feature that has a precise meaning in positioning the Dominican Republic in the global market of banana, which may be mainly due to the climatic conditions of the country, especially the Southwest region.

The plantations are located at a low altitude (between 10 and 80 m), in a dry subtropical climate, with average temperatures of 27 ° C and with a rainfall of not more than 900 mm per year. The soils are relatively good in both north and south, but of variable type. Some are sandy-loamy, requiring proper drainage. There are two production areas. The main, located in the northwest (Mao/Valverde, Montecristi and Santiago provinces) accounts for almost 94% of banana dessert exports. The rest is produced in the southwest (province of Azua), where the particularly dry climate allows the almost exclusive production of organic bananas as said.

By mid-2015, banana production of export desserts extended to nearly 16,000ha, of which 67% was organic, 13% was transitional and 20% was conventional production. In addition, 95% of total production is certified Fair Trade. This certification rate is increasing, both organic and fair. The goal is to reach 100% of organic production. In 2015, the country contained an estimated 12,000 hectares of organic bananas, and exported more than 240,000 mt (more than US$ 150 million) (FAO, 2017). More than 50% of banana exports were organic, produced by more than 1,000 growers (FAO, 2017). Approximately 95% of Dominican organic banana exports are shipped to the European Union, making up nearly 50% of its supply (FAO, 2017).

Many factors have influenced the development of organic banana production in the Dominican Republic: the low incidence of Black Sigatoka; the low use of agricultural inputs; the high market demand for organic bananas, particularly in Europe; the expectation to get better market prices; the environmental concerns in the banana industry, favouring the development of sustainable production; and the availability of resources from the international community and NGOs to promote the sector.

The Dominican Republic occupies the 22nd place among banana producers of the world and 8th place in Latin America. In the year 2011 the country exported 366 thousand tons of bananas with a value of US$358 million, which places this crop in first place, above sugar and cacao. As highlighted above, banana exporters have focused on organic production and the Dominican Republic is currently the World's major producer of this organic product. These exports are mainly shipped to the United Kingdom, Belgium, France and Germany, as well as other European Community countries. In addition to generating foreign exchange income, another important contribution of bananas to the national economy is that, together with organic cacao, it is a great source of employment in farmlands, as well as in product selection and packaging for export.

6.2.3. Banana Production systems

Production in the Dominican Republic is characterized by production systems with a low level of investment, varying technicalities. Above all, it is highly dependent on a large and cheap labour force, often of Haitian origin (more than 70%, representing more than 20,000 Haitian families living in the Dominican banana industry). Thus, productivity remains very low, with yields of less than 30 t/ha in conventional, which is among the lowest in the World. The sanitary situation of bananas, previously favourable due to an agro-ecological context naturally limiting the pressure of diseases (little Sigatoka) and pests (few weevils and nematodes), tends to deteriorate due to climatic changes (irregularity of the precipitation regime, with very dry or very watery years). The control system for Sigatoka, which relies solely on the country's climatic particularities, reaches its limits in the very humid years (as in 2011 and 2016), while risking the development of resistance, and declassification of organic producers. Conversely, the water problem has become more acute in the dry years, although the two production areas are equipped with relatively large networks of irrigation water supply channels (mainly for the production of rice and therefore secondarily for bananas).

6.2.4. Plantation size

The business of banana in the Dominican Republic it is one of rare case in which big multinationals are not directly involved. A variety of local and foreigner small firms characterise this industry. The 60% of production comes from small producers. Adobanano, the local producers' association, represents more than 1 800 firms of different size. They are organised in 21 associations, 31 enterprises, 30 independent producers and 14 exporters. The majority exports both conventional and labelled (organic and fair trade) product. The larger producers are located in the North. The association is very lively. Mao region has the largest share with 1 000 big and small producers, while Azua region is home of 400 small producers. However, the increase of major groups is the main trend.

6.3.Method

We decided to carry out a feasibility test through semi-structured interviews. In fact, interviews are the most used tool for data collection in researches conducted in health, human and social sciences. Semi-structured interviews have the strength to collect good quality information, oriented to the pursued goal (Imbert, 2010).

We flank these interviews with direct observation of operators and workers accomplishing the different steps of the production. The aim of this comparison is to cross- check both what experts referred in their narration (information present in trees), and what the interviewed persons declared. In fact, in order to obtain more robust results, our aim is to test the real presence of the features which have been highlighted by experts. Hence, by collecting direct raw data from plantation managers, we could document some implemented practices witnessed by photographs taken during the interviews.

- The selected participants

For the needs and feasibility of the study, participants were selected because of their theoretical relevance to the phenomenon studied (i.e. real practices carried out in banana plantations farmed for export). A relevant constraint was represented by the collection of context data. In fact, the delimitation of the empirical framework has to be done on the same geographical locality (i.e. a single province of the Dominican Republic state).

Conventional (non-organic) producers were selected for interviews. In fact, as the objective of the case study was to test knowledge trees and the ease of calculation of the indicator, organic producers were not considered appropriate. In fact, in organic production, following both the US regulation[28] and the EU one[29], pest diseases have primarily to be opposed trough measures and management practices aiming to reduce chemical pesticides use. As reported above (§ 6.2.2), in the Dominican Republic island, 67% of the total production was organic, 13% was transitional and 20% was conventional production (FAO, 2017). In this situation, it was not simple to find planters producing in a conventional way, and who agree to be interviewed. However, the importance of determining the impact of pesticides is still crucial for non-organic producers.

For preparing the test, our colleague Thierry Lescot[30] from CIRAD contacted producers organization for several months. We sent to the producers' associations an introduction letter presenting the thesis project and explicating in a general way the scope of the interviews. As the letter was sent on behalf of the CIRAD, and considering that CIRAD is working in contact

[28] "Crop pests, weeds, and diseases will be controlled primarily through management practices including physical, mechanical, and biological controls. When these practices are not sufficient, a biological, botanical, or synthetic substance approved for use on the National List may be used." (USDA National Organic Program, 2011).

[29] "[…] the maintenance of plant health by preventative measures, such as the choice of appropriate species and varieties resistant to pests and diseases, appropriate crop rotations, mechanical and physical methods and the protection of natural enemies of pests; […] the prevention of damage caused by pests, diseases and weeds shall rely primarily on the protection by natural enemies, the choice of species and varieties, crop rotation, cultivation techniques and thermal processes;" (European Council, 2007).

[30] Thierry Lescot is an agronomist working in the "Banana, Plantain and Pineapple Cropping Systems" (GECO) Research Unit (CIRAD). His core competencies are: agronomy and cropping systems on bananas (plantains and dessert), varietal diversity, propagation systems and quality planting material, agroecology, family farming and intensive crop management, diagnosis and pests and diseases management, quality of fresh and processed products, development, agricultural economics, projects management on research and development, animation, training.

with plantations for more than twenty years, the letter has been well received. The associations contacted their conventional planters (not all the associations had still conventional planters) and proposed us few names.

At the beginning, we preferred to interview only big planters, but, because of the scarcity of conventional planters, and we decided to interview people both from big plantations and from small ones. We perform test our trees in both cases.

- Practical implementation

The interviews took place during the month of March 2017 in the Montecristi province, Dominican Republic. I personally carried out the interviews, with the help of my colleague, Carolina Dawson[31], who is native Spanish speaker, for the translations. Carolina is perfectly proficient in banana cultivation and processing, as she belongs to the CIRAD unit involved in banana issues. The agronomical competency of the translator is important for the quality of the collected data.

We identify the four interviewed people as I1, I2, I3 and I4. I1 and I2 refer to big plantations managers, while I3 and I4 refer to small plantations ones.

The four persons interviewed were an owner of the plantation (I1), a president of a company owner of a plantation (I2), a plantation foreman (I3), and a plantation supervisor (I4). I3 were supported by the technical supervisor of the association of producers in answering our questions.

Each interview lasted an average of 2 hours. The venues were: the house of a plantation owner (I1); the head office of the plantation company, located next to the plantation itself (I2); the packaging plant (I3); the area at the entrance of the plantation (I4).

I1 and I2 accepted that their interview to be recorded.

The interviews allowed us the collection in Spanish language of a particularly dense material, but also to discover the work environment and workplace of operators.

[31] Carolina Dawson is a fruit market analyst at the Market News Service in the GECO Research Unit (CIRAD). This service provide knowledge about the functioning of banana markets, development of decision aid tools for sector stakeholders.

We prepared a first English version of the interview guideline, to interview plantation managers (Annex 2).

Given the low level of literacy of the plantation managers, and because they have been interviewed in Spanish, we translated the interview guide in Spanish (Annex 3).

- The practice of observation

At the same time in which we carried out the interviews we also asked to interviewed people if it was possible to observe, also in part, operators and/or workers carrying out the different plantation steps, explaining that I am a PhD student and assuring we will use information and photos only for research aims.

I1 allowed us the possibility to visit his plantation and his packaging plant in the days following the one of the interview. He chose this day because it was a harvest day and we had the possibility to observe this part of the production and the packaging plant in functioning.

I2 allowed us the possibility to visit the plantation the same day of the interview. It was a harvest day and we had the possibility to observe post-harvest treatments. In the following days I2 conduct us to a landing track of one of the service providers treating banana and rice plantations. We had the possibility to visit the landing track only because of I2's commitment.

We interviewed I3 at the packaging plant, that was functioning. In this occasion, we had the possibility to observe the post-harvest treatments' step. I3 did not allow us permission to observe other steps.

All these people allow us to take photos during the observation.

I4 did not allow the possibility to observe any production step.

- Guidelines for the interviews

The interviews were divided into five parts:

1. Introduction, consisting of nine questions. In this first part, we collected general information about the plantation and about the interviewed people such as his/her role in plantation (he/she is the owner of the plantation? or he/she is a plantation employee?), plantation extension, age of the plantation, how many workers are employed in the plantation, and if the producer is part of a producers' association.

2. Plantation particulars, consisting of sixteen questions. In this section, we investigate in a deeper way who is the owner of the land[32], which products are cultivated in that plot of land (only bananas, or not? This is very important for our concern because of the quantities and typologies of chemicals used in the plantation), and if bananas farmed in that plantation are for export or not.

   In this part, we gather information about the implementation of general cultivation practices which are traceable in our knowledge trees, such as if a service provider is used to make pesticides application, or about the presence of a "phyto team" directly selected among the plantation workers (the operators) and how many elements this team is composed of. If present (both the service provider and the "phyto team"), in which step are they used, and for how many times per year? In particular, for the "phyto team" there was a question about which type of PPE[33] do they use (boots, suits, glasses, etc.). So, we ask questions about the customary practices implemented in the plantation, e.g. if there is a specific place where the plant protection products are stored, if there is a specific place where the PPE not already used are stored, where the operators can put their clothes when they wear the PPE, if there is a management process about used PPE (e.g., Are they stored somewhere? Are they wasted somewhere? Are they re-used?).

   At the end of this questions' section, we collect information about:

   - The "PPE policies" (§ 4.1.3): if trainings on pests' harmfulness and/or pests linked diseases are organized, or if bonus/cash payments are provided to encourage operators to wear PPEs,
   - The technical gestures for the protection of plants (defoliation, etc.) that can avoid or reduce use of chemicals.
   - The role of the producers' association (if the producer is part of an association) in the plant health activities (e.g., training, collective pesticides buying).

[32] In Dominican Republic, the land is largely State-owned, and the citizen cultivate those plots with permissions. The State does not dispose these lands to the privates in order to avoid the small properties to be sold for subsistence.

[33] Posing this question, we expect answers that highlight a behavior that complies with the law or an under-compliant one. We aim at testing also if managers are aware of what happens inside plantations and if they can explain the reasons for bad practices implementation in plantation, regarding PPE wearing (we are aware of these bad practices from expert narration).

3. In the third part, we investigated which of the plantation steps (§ 4.1.3) are implemented in a single crop. For the main steps, we collected information about products used, frequency of treatment and activities.

   At the end of this section, we investigated the methods of preparation of the mixture, and the adopted methods to apply different pesticides.
4. The fourth section regards information about the cleaning task[34]. We investigated the presence, or not, of an instrument cleaning phase, with what frequency it is carried out and by whom, the place, and, finally, the presence of a waste water management processes.

   The last part of the interview guide contained questions for plantation workers, about their literacy level, the use of PPEs, eventual raisons leading to do not use them, working hours, time off after spraying.

- The handling of interviews

The contents of the recordings of the 2 interviews and the notes of the 4 interviews were fully transcribed in Spanish, then checked, translated in English and controlled. There were also valuable handwritten translations produced by the interpreter during the interviews and my own notes, written immediately during each interview. The intention was to carry out a “dense”, exhaustive, microscopic, interpretive description of the flow of the discourse and to preserve it "in legible terms".

- The data analysis method

Data collected through the interviews were transcribed and compared with what was reported in the knowledge trees (§ 4.4.4). Furthermore, to cross-check results, the experience deriving from the direct observation of operators and workers was compared with reports from the trees and with the interviews. Indeed, we are aware that interviews contents stem from the representations of the interviewed people. So, we need to cross-check the interviews contents thanks to observed practices, in order to draw nearer the actually implemented practices.

We collected data regarding the plantation practices. On the base of the information got during the interviews, we traced the production system under analysis in our trees, to confirm (or not)

[34] As explained before, we didn’t collect information about cleaning task from the experts because they declared they didn’t experience it during their career.

that their structure reflects the structure of the different plantation steps. With the information collected during this test, we have also the occasion to complete and refine the description of practices reported by the experts (e.g., adding different tool or different treatment technique).

Thanks to data emerging from the interviews and collected during the observation phase, we would be able to calculate a "human impact" indicator. During the collect, we have paid attention to check the minimum data which are mandatory for the manager to perform the assessment of his/her banana production system regarding workers health.

6.4. Results

Here are exposed the first results of the feasibility test, which will be discussed in the next section (§ 6.5).

6.4.1. Minimum Data requirement

What are the minimum data needed by managers to assess the consequences of pesticide use on worker health, in one given production system? Regarding the calculation and referring to the knowledge trees' (§ 4.4.4) and the indicator's structure (§ 4.4.6), the managers need the following data:

How is the work organized in the plantation? For example: does it exists a "phyto team" and do the other workers carry out the other technical gestures (organized in teams per parcel or not), or are teams working by parcel, and does everyone carry out all the actions useful to farm bananas?

How many times the plantation was treated during the time he/she chose to adopt in the study (e.g., last year)? which product was applied and in which way (e.g., 2 treatments by plane with urea and 10 backpack sprayer treatments with paraffinic oil)?

How is the mixture prepared? For example, what is the frequency of execution of this task, does it exist some specific installation (if yes: which one?); who is in charge of preparing the mixture, in which place does the preparation take place?

How is the instrument cleaning phase managed in the plantation? The managers have to collect information regarding the existence of a waste water management process, the frequency of implementation of the task, the person in charge of it, the place in which cleaning takes place, and which products are used in this task.

6.4.2. Actual practices and knowledge trees

We confirm the information reported by experts during the consensus method. We arrive to this conclusion after the managers' interviews. Managers referred they implement in their plantations the same step the experts referred to us during the consensus method. For example, regarding treatments against Black Sigatoka, as referred by experts, they have a service provide who treat by plane, and, when they believe the pests is augmenting too much they reinforce aerial treatment with manual treatments trough backpack sprayer (referred by all the interviewed people), or with mechanical treatments (I4 referred about *motobomba*, a sort of quad).

We confirm the way the trees were structured. In fact, interviewing the plantation managers, we found out that managers are perfectly comfortable in reasoning following the different section of our interview guideline, built following trees' structure. Moreover, after some general question about work organization (in the "Plantation particular" section), in the "Task evaluation" section, we have given managers the opportunity to speak freely, and they narrate the different operations they carry out in the production, following (also chronologically) the different knowledge trees we devised.

It is possible to trace actual production systems in the knowledge trees. Nevertheless, conditions are different depending on the size of the plantation. This operation appears quite simple in big planters because of their conscience of what happens in their plantations. The situation changes when we analyse the case of little planters. In fact, the technicians appointed by the producers and/or exporters' associations, visit on a weekly basis all the associated producers (in particular the smaller ones) to supervise the plantation and to advise for treatments and products. From the context analysis emerged also frequently that these technicians do not have the requisite expertise to advise producers at best.

Above all, small producers are not capable to manage the complexity linked to banana's market (§ 3.1); the necessity and frequency of treatments; the more suitable pesticide for the specific plant disease (also depending on to the pedo-climatic conditions). They are "victims" of the pressure of pesticide firm, wholesalers and producer associations' technicians. They sometimes treat their plantations when is not necessary and use chemical products, when non-chemical products could be suitable. This pressure can lead to decisions entailing a harmful impact on workers' health.

From the direct observation of operators and workers in the plantations[35] emerged the idea that the PPE are generally not worn, in different steps of the production process. In Figure 5.1 (Annex 5) we document how the preparation task is carried out: the task takes place in the middle of the plantation, where the application of the herbicide is needed, and there is no specific installation for preparation. The same operator who applies the mixture was in charge to prepare it. No specific PPEs were worn during this task. In Figure 5.2 (Annex 5) we observe the same operator applying the herbicide with a backpack sprayer, and wearing boots as unique PPE. No cleaning task was carried out. Regarding the use of PPE, people operating in the banana Dominican context reported that PPE are not available *in loco*. In fact, the product wholesalers do not sell the adapted protective equipment. This is certainly a major obstacle to the spread of the use of these protections.

6.4.3. What new did we learn also?

After these interviews, we are able to create a sort of "classification by importance" of the different steps. In fact, if data are missing, we are able to recommend the practitioner to focus on some of the nine steps only.

From the interviews emerged the idea that the plant protection step, particularly the fungicide treatment against Sigatoka disease, represents a crucial phase for frequency of treatment and toxicity of products. This phase is implemented by aerial fungicide application and supplementary backpack treatment (as reported in Annex 4). The interviewed person declared that they treat on Sunday only to avoid workers' presence in the plantation. Nevertheless, when visiting two landing tracks, we have observed the aerial fleet of one of the two service providers. Knowing that the planes treat rice plantations also, it is improbable that all the banana plantations can be treated on Sunday only.

In the packaging plant, a hotspot was represented by the fungicide treatment on the crowns, before bananas to be packed. In 5.3 (Annex 5) we observe an operator applying a fungicide on banana crowns without mask and glasses. Another ascertained issue is observable in Figure 5.4

[35] The observation was possible only in I1 and I2 plantation, for the I3 case we had the occasion to observe only the packaging plant step. In I4 no observation was allowed.

(Annex 5): an operator is using a t-shirt like a PPE instead of a mask. Misuse of PPE is one of the main causes of pesticide exposure of agricultural workers (Feola and Binder, 2010).

About the general competences possessed by producers, it seems that producers are not well-informed regarding certification requisites, even if they already have the certification at issue.

Producers declared a rejection of about 5% (that is the official datum) of banana by the certification body, but the real datum is around 10-15% of the total production (Lescot, 2017). It may suggest that they are aware of the inefficiencies of their production systems and they try to mask it.

6.4.4. Testing is quite fast

By tracking the data collection on different plantations, we realized that testing the process is relatively a fast mechanism. Tracking the process and monitoring systematically the entity of the risk would help the manager to obtain fast data to assess the presence of risk on health, and this will be helpful to develop our indicator. In fact, thanks to data emerging from the interviews and the observation phase, we are able to calculate a "human impact" indicator. A first result of our analysis in this sense is the relative fast pace at which data can be collected, in the case of banana plantation. This aspect is definitely interesting for the application, particularly for its feasibility. It denotes that the banana plantations represent an excellent example for our assessment method, due to the presence of standard and quite plain processes. Hence, this conclusion can be generalized to all the plantations. Indeed, in all our cases, the interview and the monitoring by direct observation took no more than few hours.

Despite the easiness of tracking the production system in the knowledge trees, the trees are not devised to bring the practitioner an evaluation of the system, but only to trace the different steps, sub-steps, actions and tasks carried out in farming bananas. In particular, they trace the three tasks (preparation, application and instrument cleaning) taking into account: work organization (existence or not of "phyto teams"), existence of PPE policies (e.g., training or cash bonus to the operators to encourage them to wearing the PPE), different application methods (e.g., gun vs. backpack sprayer to apply herbicides to destruct the old plantation), possible installations to prepare the mixture (e.g., open tanks or closed automatic mixing tank) and cleaning facilities.

From the case studies, it is obvious that managers need a tool to evaluate the performance of their production system, in comparison with another one, and based on risk for operators' health. This need was confirmed by the necessity for managers to become aware of the impact of the plantation practices on workers' health. If they understand it as soon as possible, they will be in position to find cultural alternatives, less affecting the operators' health, but not compromising the regular farming of bananas for export. Considering these concerns, the necessity of devising an indicator, as reported in § 4.2, has emerged.

6.5.Discussion

As exposed above, the feasibility test had several aims. We turn back to each one, in the following paragraphs.

1. Is it possible to identify one given production system?

We aimed at identifying the given production system in a real case, among the production systems depicted by the knowledge trees. After collecting data from interviews, we tried to trace different production systems in the knowledge trees. From this test, it emerged that the devised knowledge trees are capable to include the actual production systems carried out in Dominican Republic. In fact, we were capable to follow –in the knowledge trees- the description of the production systems provided by the interviewed persons when answering to the sections 4, 5 and 6 of the interview guideline.

The only discrepancy between the knowledge trees (devised from experts' narration) and the reality observed during the feasibility test, was in the preparation task of the aerial treatments against Sigatoka. Despite in the trees we reported that, for aerial treatments, the preparation task takes place only in closed automatic mixing tank, during the visit to the landing track, we have found open automatic mixing tanks also. This new option was added to the specific tree.

2. Are the data easy to collect? For who?

From the direct observation of agricultural workers in the plantations and from the context analysis, we find that data for "human impact" indicator calculation are quite simple to collect and to manage on their own, in particular for big planters.

In fact, small planters appeared not to be qualified to manage this type of data for the reasons presented in § 5.5 and, more in general, because of the low literacy level. Moreover, they have not enough conscience of the risk that agricultural workers run at workplace, to be the target of the indicator developed in this project.

For these reasons, we suggest to re-define the target of this tool. Actually, the right target are the big planters, having the means to understand the risk to whom workers are exposed, to collect the useful data, to calculate the indicator, and having the decision autonomy to modify the production system to reduce this risk, and the producer associations' technicians. Generally, big planters have the means to collect the useful data (number of treatment repetitions per year, number of operators involved, AOEL and w_j), while small planters are maybe neither able to consult online databases (to obtain the AOEL of the specific product) nor able to trace the production system in the trees (to obtain the w_j value per each task of the entire production system). Also, the calculation of the indicator may represent an obstacle for small producers. Finally, as suggested by the technician, small producers might not have the autonomy to modify the production system.

Indeed, there is a large number of superstructures like producers' associations, exporters, and exporters' associations, which overlap. These superstructures "hem-in" the producers in a severe bureaucracy that impede them to freely act. In this situation, big planters have the ability to act equally autonomously, while small planters are entirely dependent on producers' associations and exporters for all the company's decisions and actions (e.g., work management practices, products to be used, decisions about necessity and frequency of treatments, etc.).

Consequently, our indicator could find its target in big producers and producer associations' technicians.

3. Is it easy to find alternative routes?

The first step of our tool implementation is to trace actual production systems in the knowledge trees. This operation allows the practitioner (big planter or producer associations' technician) to identify the hotspots of the production systems. We define as "hotspots" the steps or, more particularly, the sub-steps that represent a major risk for workers' health. These sub-steps can be carried out through different actions. As reported in § 5.5, the interviews highlight that a hotspot is often represented by the plant protection step, in particular by the sub-step of treatments against Sigatoka.

Once traced the production system in the trees, and identified the hotspots[36], the practitioner can find and evaluate in the knowledge trees the possible variations of the system. He/she can

[36] A « hotspot » is defined as "an area to be prioritized for action" (Life Cycle Initiative, 2017) (see more at: http://www.lifecycleinitiative.org/activities/phase-iii/hotspots-analysis/).

therefore choose a new itinerary, with the aim to be less risky for workers. In this way, he/she has an evaluation related to the specific plantation context, including constraints linked to pedo-climatic conditions, certifications' requests, exporters' and associations' rules, etc. He/she can evaluate the range of consequences stemming from new itineraries on the production system, in terms of work organization, firm policies, and different agreements with service providers or wholesalers. Also, the producers' associations can, in this way, evaluate the range of consequences in providing different services to their associates, like serious training to associates' workers, rules limiting the use of a specific product, or promoting collective purchases that can made economically convenient to use a less toxic product and/or a different application tool. The associations can also assume the role of service provider for not-aerial treatments. In this way, they can train the "phyto team" about risks of pesticides and about wearing PPEs, and organize treatments to the associated, following a shared program. This would allow treatments to be carried out by a more professional staff than nowadays.

4. New issues

As reported in § 6.5, producers (and in particular the smaller ones) are not capable to manage the complexity linked to banana's market (§ 3.1); the necessity and frequency of treatments; the choice of products more suitable to the specific plant diseases (also in function to the pedo-climatic conditions). They are "victims" of lobbying from pesticide firms, wholesalers and producer associations' technicians, who push to treat the plantations also when is not necessary. In the same vein, they treat with chemical products when also non-chemical products, or less toxic ones, could be suitable. Moreover, there is a dense network of superstructures that limit the producer's decision-making autonomy. For instance, this pressure is also at stake in the participation to research projects (Lescot, personal communication): some small producers are participating in a research project on sustainable agriculture (*agriculture raisonnée*). In this project, researchers monitored the plantation and the pressure caused by different pests. The researchers advised producers when it was the moment for treating with a specific product, because the pressure was high enough to request a pesticide treatment. Unfortunately, the cited project did not produce the expected results, because the producers treated also when the pressure was low, and/or with quantity and frequency too high for the specific case. This behaviour can be explicated by the lobbying exerted by wholesalers on producers via producers' associations.

It could be interesting to investigate if this lobbying entails the use of products which are more toxic than needed, and/or the use of a specific method of application (like the one the wholesalers want to sell). As reported in § 4.1.5 our indicator provides an evaluation limited to the risk for operators only, and ignores the risk run by other agricultural workers. It could be interesting to investigate if and how results are affected by the choices operated under pesticide lobbies' pressure.

In this context of constant pressure on producers (particularly the smaller ones), the availability of a tool (as the one we present in this thesis work), that is capable of evaluate the alternativity of the choices and to determine the choice of a production alternative instead of another one (following the principle of the minor pesticide risk for workers, in the case here presented operators), it might be of help for managers to try to exit this pressure.

6.6. Conclusion of the discussion section

This study allowed the observation of some critical aspects of the feasibility test, for the banana production process in Dominican Republic. It highlights that observations and interviews' contents are close to what experts narrated. At the same time, the direct observation helps defining a framework in which sets of information are collected. This information is useful to develop evaluation tools about pesticides' impacts on farmworkers' health. This goal is not simple to be reached, since it is requested to be both comprehensive and simple to be used. In fact, it is not simple to realize a simplified scenario in which managers have to be aware both of the existence, both of the consequences on the efficacity of the production process of mismanagement practices

Our impression, in fact, is that there are cases in which managers do not have a precise idea about risk linked to pesticide. At the opposite, in other cases, there is a lack of decisional tools, which would allow managers to manage pesticide applications with inexpensiveness. The development of managers' conscience about this problem could promote the use of PPEs that are sometimes present, but that are ignored by the operators to date.

Chapter 7: Discussion

In this discussion chapter, we deal with the limits of this work (§ 7.1), with the issue of model generalization (§ 7.2), before tackling the recommendations section (§ 7.3). This will encourage us to deal with the DALY issue (§ 7.4), and more generally with the possible contribution of this work in the engineering field of social life cycle assessment (§ 7.5).

7.1.Limits of this work

As it is always the case, some elements could be improved in future works. The limits linked to this work can be classified into two categories: theoretical (§ 7.1.1) and limits to the application (§ 7.1.2).

To facilitate the discussion about the limits of this work, we report here the indicator presented in § 4.1.5.

$$Human\ cost_{operators} \text{for one action} = \left(\sum_{j=1}^{3} N_{o_j} N_{t_j} X_j \frac{1}{AOEL_j} \right)$$

Equation 6 - "Human impact" indicator

with:

- j which means one of three tasks: preparation, application or cleaning
- N_{o_j} represents the number of operators involved in this task
- N_{t_j} denotes the number of times that the task is repeated, under the same conditions, on the perimeter of the space-time computation.
- X_j reflects the degree of operator exposure. It was found out in the knowledge trees based on a specific task at a specific point of the production system.
- $AOEL_j$ identifies the AOEL of the product used in the task j.

7.1.1. Theoretical limits

Workers' health may be affected in different ways. Many causes of risk are not linked with pesticides indeed, however many of these are linked to pesticides exposure at the workplace. In particular, we do not take into account general exposure to chemical products (e.g. exposure to cleaning products, as bleach and detergents). In the same way, we do not consider neither pathologies which are not directly stemming from pesticide exposure at the workplace (e.g. muscular-skeletal pathologies, pre-existing genetic disorders), neither impacts due to exposure in a domestic context (e.g. while gardening).

Thus, our study deals only with impacts caused by occupational exposure of operators to pesticides, in the case of plantations of dessert bananas farmed for export only.

The first category groups limits linked to theoretical aspects we didn't had time to deepen during this PhD work, and that could be bridged in a subsequent research work. The first important limit highlighted is the additivity of the indicator. We make the computation as if the health damages were only cumulative (because of different tasks and various occasions to be exposed), so as if what matters is the number of exposures. Nevertheless, it is likely not the case. There are some evidences than sometimes, health damages are more linked to the real total duration of exposures. This factor is not involved in the indicator. Moreover, we neglect the harmful "synergy" of the different substances at which the same operator could be exposed. So, the effects of pesticide exposure in the three considered tasks should not be represented by an addition. Most studies have focused on risks for single pesticides, but farmers are typically exposed to several different pesticides over their lifetime. Multiple pesticides could be used simultaneously or during the same growing season, but not necessarily during the same application. For this reason, it is important to distinguish effects caused by each pesticide from combined effects (Kachuri et al., 2013). The two exposure metrics we consider (number of pesticides used, and days per year of pesticide use) have been already used by some authors (e.g., Kachuri et al., 2013). Nevertheless, a potential limit of our approach is an under or ultra-estimation of combined pesticide effects, both in terms of multi-pesticide exposure and in terms of multiple exposures.

In fact, primarily, a differentiation between cancer and non-cancer effects must be done. Cancer and non-cancer health effects have traditionally been handled differently in quantitative risk assessment (QRA). For non-cancer effects, one sets the assumption of a "safe" exposure threshold, below which no effects are expected (i.e., the no-adverse-effect level). This is in keeping with the historical toxicological paradigm that "the dose makes the poison." Cancer risk assessment uses a linear[37], no-threshold assumption, because cancer can be produced through a genetic mechanism, suggesting that even a single genetic error, if perpetuated, could lead to tumour formation. In more recent years, regulatory initiatives (e.g., US EPA, 2001; 2002) suggest a harmonized, probabilistic/linear approach for non-cancer health effects also. Proponents of this approach cite variability in human susceptibility as an argument against thresholds (i.e., some individuals may be exquisitely sensitive at exposures well below conventional threshold levels). Because of the debate in the scientific community, the authors retain this point as a possible drawback of the developed method. A more deepened consideration of this aspect has to be included in a future update of this work.

The second limit is the only partial perspective the indicator results provide. In fact, to completely evaluate production choices on the base of pesticides impact on farmworkers we should have an evaluation of the impact both on operators and on generic workers. In this way, the choices taken on the base of the “human impact” indicator would be more complete. In fact, often, a practice less unsafe for operators’ health may be more harmful for the other workers’ health. For instance, aerial application impacts on one operator only (the pilot), but, if the not-entry delay is not respected, farmworkers could be inside or next to the treated parcels, so the whole impact produced could be equally severe than a manual application made by more operators without workers in the treated parcel. To perform a very complete evaluation, it would be better to include also the residents’ perspective. In other words, it would be necessary to develop an indicator also for the evaluation of the risk for residents. In this way we would obtain a more complete evaluation of pesticides’ effects on health in the agricultural phase.

The indicator could be refined through the insertion of weights regarding morphological characteristics of the parcel/plantation considered. In fact, the presence of particular conditions (e.g., the presence of a slope) often entails the misuse of the application tools. For example, operators working on the slope could be brought to place the application lance anteriorly to their body, instead of posteriorly, as it would be the good practice to do.

A further factor that would be interesting to take into consideration would be the role of climate conditions. Indeed, climate conditions such as temperature and humidity, influence both the fate of chemical products and the behaviour of workers, in both wearing and application tools’ use.

We regret also that the indicator doesn’t account for the different impacts of the same quantity of chemical on different persons. The developed indicator does not include factors to take into

[37] Two quantities are in linear relation if some form of direct proportionality exists between them.

account personal characteristics of operators (e.g., body weight, previous pathologies that could impact the effects of chemical exposure, etc.). Nevertheless, the ambition of the indicator is to roughly compare the effects of different ITKs for groups of workers, and not to individuate effects for one worker alone.

Finally, another limit is represented by the aleatory effect of pesticide on people health. In fact, in each phenomenon there is an aleatory part that cannot be planned.

7.1.2. Limits to the application

The most evident limit of the results of this research work lies in the fact that both knowledge and decision trees, and the indicator were developed on the banana plantation case study only. In order to be implemented in different crops, the developed method has to be adapted to crop's peculiarity. In particular, the data collection phase must be done by eliciting experts of the new crop. Indeed, not only the value of the X_j will vary. The structuration of the information to be collected may vary also on the base of different crop's peculiarities. We can imagine it could be possible to vary also the subjects to involve in the consensus method, in the hypothesis there are other figures informed relative to the actual plantation practices. In our study implementation, we interviewed researchers in various disciplines, but we can hypothesize to involve other expertise, such as managers, consultants, etc.

Another limit that has to be highlighted is that the health impact calculated by the proposed indicator cannot be compared to other health impact (e.g., other toxic emissions, occupational injuries, and socio-economic health impacts through the Preston (Feschet et al., 2013) and Wilkinson (Bocoum et al., 2015) pathways

7.2.Model generalization

While this research work was developed considering the banana case study, the ambition is to set a working method replicable also for other crops.

Banana was chosen as a focus for this research because of the importance of this product for several Developing Economies, and, more in general, for the World agri-food market (as reported in § 3.1.1). Another reason for this choice was the substantial homogeneity of banana plantations practices into the World. This homogeneity concerned essentially:

- Practices implemented in farming banana for export, in term of production phases (the nine we identified in § 4.4.4).

- Pesticides application tools (e.g., plane, quad, backpack sprayer), identified during the consensus method and reported in both knowledge and decision trees (Annex 2 and 3).
- Chemical products used. In fact, despite the different regulations in force in different parts of the World regarding admitted pesticides for banana farming, plants suffer the same diseases and there are no much active substances useful to contrast these diseases.
- Technical gestures, capable to avoid/reduce pesticides application, identified during the consensus method and reported in both knowledge and decision trees (Annex 2 and 3).

7.2.1. Generalization to other crops

To find out the same indicator implemented to other crops, a study of actual practices carried out in plantation/ field is fostered. To do this it is advisable to individuate how to collect data on real practices implemented in plantations/field (e.g., national databases, previous studies, experts' narration).

Moreover, in function of the great diversity of farming practices in the various parts of the World for the same crop, we can hypothesize to take as reference a small geographical scale.

As a handbook guide for future practitioners, we encourage to focus on the following potential differences, compared to the specific method developed in the present research work:

- Other crops may be characterized by a broad set of possible practices to farm the product object of evaluation, in terms of variety of alternatives to carry out the single plantation/sowing phase in function of several variables such as: climate conditions (e.g., presence, or not, of a greenhouse that implies an indoor pesticide exposure), destination market of the product (that may have particular requests impacting the production phase).
- Different pedoclimatic conditions could imply different practices. In particular, different heat, humidity and pedologic conditions may lead to different pesticide fate and determine different relevance of routes of exposure.
- Pay particular attention to the hotspot identification. For banana case, the main hotspot we identified was the "not wearing of PPE", despite in other contexts, the source of potential hotspots may vary from the excessive application of chemicals to the absence of "PPE policies".
- Investigate the presence, or not, of what we call in this work "PPE policies" (§ 4.4.4). More in general, we refer to the presence/absence of policies to encourage the reduction of an identified hotspot, both to be compliant with regulation and to reduce a negative phenomenon.

- As the culture examined changes, the technical gestures implemented to avoid/reduce the application of pesticides will also change. All of these practices must take place into the knowledge and decision trees that will be developed.

7.2.2. Generalization regarding different Countries

In the perspective of generalization of the method here developed for crops farmed in different Countries, the first aspect to take into account are the different pedoclimatic conditions peculiar for single Country or for regions. Resuming what was stated in § 7.1, it could be devised a pool of weights considering pedoclimatic conditions: weights taking into account morphological characteristics of the plantation (e.g., presence of slope, plants density), and climatic conditions (e.g., heat and humidity).

Another field to consider in adapting this method to other Countries, in particular Developed Countries, is to consider the different legislations about pesticide use. While in Developing Countries (where almost the whole of banana production is farmed) there is a no-strict regulation about pesticide use and PPE wearing, in other Countries there could likely be a stricter one. This aspect must be taken into account to highlight, during the data collection phase, possible violations of regional/national/international rules, to be reported in the results communication.

Another variable to take into considerations are different social conditions, e.g., low or high labour cost that could influence the adoption of different productive choices (mechanization vs. manual).

7.2.3. Generalization in function of real exposure to pesticides

In this work we devised the "human impact" indicator (Equation 6) adapted to banana farming for export. In this specific context, both the literature analysed, and the expertise collected reported that usually the operators do not wear PPEs. Moreover, we elicited the experts to collect information about the real practices implemented in plantation.

In the perspective of adaptation of this method to other crops, a system of weights connected to the different PPE could be devised. The idea could be to combine the current indicator with another one evaluating the impact of the PPE worn by operators, as in the example presented in Equation 7.

$$Human\ cost_{operators} \text{for one action} = \left(\sum_{j=1}^{3} N_{o_j} N_{t_j} X_j \frac{1}{AOEL_j} \right) - f(\sum weared\ PPE)$$

Equation 7 - Adaptation of the "human impact" indicator to the possibility of PPEs worn by operators

As exposed above (§ 7.1.1, 7.2.1) different pedologic characteristics may lead to different application practices and bad practices (e.g., the application lance could be placed anteriorly to the operator body, instead of posteriorly). Also, these case study's specificities have to be considered when developing a ranking score to make comparative performance evaluation, e.g. between two different productive ways. Recalling Equation 6, we can hypothesize to add another adjustment factor for pedoclimatic conditions (Equation 8). We propose to add (and not to subtract) the adjustment factors because they represent an additional risk to whom operators are exposed.

$$Human\ cost_{operators} \text{for one action} = \left(\sum_{j=1}^{3} N_{o_j} N_{t_j} X_j \frac{1}{AOEL_j} \right) - f(\sum weared\ PPE) + f(heat) + f(humidity) + f(slope) + f(other\ pedoclimatic\ conditions)$$

Equation 8 - Adaptation of the "human impact" indicator to the possibility of PPEs worn by operators and to pedoclimatic conditions

7.3.Recommendations for conceptualizing innovative cropping systems

In a wide context, agricultural policymakers are addressing the sustainable development issue by designing new agricultural systems. Farmers are ultimately asked to make deep changes at field scale. Designing cropping systems has previously been done using prototyping methodologies. However, sustainable dynamics imply considering changes at larger scales than the parcel, like farm and region, as well as creating feedback and facilitating participation of all the stakeholders involved in the process. As the sustainable development paradigm takes over the world, agricultural policy makers are responding by calling for more sustainable agricultural systems. In this context, redesigning cropping systems has become a major challenge for agricultural professionals, and for the last decade, agricultural researchers have been developing prototyping methods and tools to facilitate the design of innovative cropping and farming systems (Le Bellec et al., 2012)

To approach this argument, it is useful to focus on a definitory task about what is an innovation and what kind of innovation we are dealing on.

"An innovation is an idea, practice, or object perceived as new by an individual or other unit of adoption." (Rogers, 2007)

As in this epoch, our agriculture is more and more prone to an intensive, industrialized and high-concentration technology, it might be interesting to define also what a technology is:

"A technology is a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome. Most technologies have two components: hardware, consisting of the tool that embodies the technology as a material or physical object, and software, consisting of the knowledge base for the tool." (Rogers, 2007)

Our research work takes its place in the "software" part of the technology. In fact, in this work, we collected information and developed a tool, to try guiding decision makers in developing cropping systems less risky for farmworkers (in particular operators).

Otherwise, focusing on the "hardware" part of the innovation technology, we will focus on possible recommendations to develop innovative cropping systems considering also the pesticide-linked risks for workers.

"The characteristics of an innovation, as perceived by the members of a social system, determine its rate of adoption. Five attributes of innovations are: (1) relative advantage, (2) compatibility, (3) complexity, (4) trial ability, and (5) observability." (Rogers, 2007)

When developing an innovative cropping system, one should never forget the fact that this will be inserted in a pre-existing social context and that, in many cases, it will produce upheavals in this latter, in particular in the communities centred on the considered agricultural activity.

Following the five principles exposed here above, we can state that, when an innovative cropping system is devised, the practitioner has to consider these points:

1. Relative advantage. The innovation proposed has to produce a tangible advantage for the different community stakeholders, mainly workers and residents (often there are overlap between the two categories: e.g., a plantation worker often live near the plantation). In this way, the community should be more collaborative in adopting the new prescriptions.
2. Compatibility. The innovation project may consider the starting situation and adapt to peculiarities and previous prescriptions, if possible.
3. Complexity. It has to be reduced as much as possible, in particular in what workers have to change in their daily work. In this way, the rate of adoption of a little variation could be quicker compared to the rate for a bigger one. Training courses have to be programmed specifically for workers, in order to involve them in the correction phase, on the base of their direct experience with both the old and new prescribed practices.
4. Trial ability. A transition period has to be programmed both to correct possible errors, and to allow adaptation of workers/residents.
5. Observability. After the adoption of innovation, a careful observation phase must be carried out regarding the implementation rate and the corrective phase.

In this perspective, stakeholders have to be involved from the innovation design phase, through the implementation, until the correction phase. This latter could be defined as a "re-invention phase"[38].

7.4.DALY issue

Hofstetter (1998) introduced the DALY-concept in LCA (Life Cycle Assessment), which is based on the work carried out by Murray and Lopez (1996) for the World Health Organisation.

When equal weightings are applied to the importance of 1 year of life lost for all ages and when any discount for future damages is disregarded, DALY is the measure of the health damage expressed by the sum of the years of life lost (YLL) and the years of life disabled (YLD):

$$DALY = YLL + YLD$$

With $YLD = w \times D$

[38] "Re-Invention is the degree to which an innovation is changed or modified by a user in the process of its adoption and implementation." (Rogers, 2007).

Where *w* is a severity factor between 0 (complete health) and 1 (dead), and *D* is the duration of the disease.

A sure advantage in adopting a DALY approach is that it enables comparison between different types of health impact.

Although the concept of DALYs has proven to be a useful metric in the assessment of human health damage in LCA (Hofstetter 1998), the actual calculation depends on the following subjective assumptions:

1. DALYs refer to a specified region and time frame, such as the world in 1990 (Murray and Lopez, 1996). Thus, applying world average DALY estimates in the calculation of characterisation factors implies acceptance of the assumption that damage to human health due to life cycle emissions can be represented by world averages. For LCA case studies focusing on region-specific human health impacts, however, such DALY estimates should be used with care. Taking another region in the world as a starting point for the DALY calculation may cause a change in the results (Goedkoop et al., 2009a).
2. Secondly, in most LCIA methodologies, DALYs are calculated without applying age-specific weighting and without discounting future health damages. These two assumptions, however, are a matter of debate.
3. Third, the use of YLDs includes a subjective assessment of the weighting of health disabilities (Krewitt et al. 2002). The difficulties linked with such an assessment explain why some of the LCIA methodologies explicitly exclude YLD from the damage assessment.

The major disadvantage is the treatment of deaths in the older population (Murray 1994).

However, taken into account the structure of the "human impact" indicator and the way of its construction (e.g., experts' elicitation via a consensus method and focus on real practices), the authors do not envisage translation into a DALY measure.

7.5.Social Life Cycle Assessment (S-LCA)

The goal of sustainable development is human well-being, contributing to the needs of current and future generations. In the field of product and process assessment, some methodologies, techniques and tools have been developed, mostly supporting policies and strategies for the social, economic, or the environmental dimension of sustainable development. In the language of economists, these tools are aimed to assess internalities[39] and externalities[40] of products/services along their entire life cycle (UNEP/SETAC, 2009).

One usual way of interpreting sustainability is to invoke three pillars. In this particular view, the economic pillar of sustainability is expected to be evaluated through the Life Cycle Costing (LCC) methodology. The environmental one, instead, is covered by the most used tool: E-LCA. Its practitioners evaluate product life cycles according to "Areas of Protection" (AoP). These are "domains" that need to be preserved and indicate the impact categories of value to society. There is consensus on the nature of AoP in E-LCA (human health, natural resources, natural and man-made environments).

The S-LCA (Social Life Cycle Assessment) can be interpreted like the methodology aiming to evaluate externalities and internalities regarding the social pillar. In fact, it has been suggested first by scientists (O'Brian et al., 1996), willing to develop a method analogical to E-LCA, but devoted to analysis of social instead of environmental impacts. Dreyer et al. (2006) proposed to introduce the AoP "human dignity and well-being", while Weidema (2006) distinguished two areas of protection: "human health" which has intrinsic value, and "human productivity" which is instrumental. However, Jørgensen et al. (2008) pointed out that, in general, there is no theoretical thinking about the underlying models. This lack is a source of confusion. It does not make it possible to define what counts in the social world, nor to define the nature of the impacts. The result may be an empirical choice of indicators which constitutes "perverted lists", which are non-homogeneous and different from one approach to another. Finally, it is not possible to articulate the AoP in order to have a dynamic reading of the state of sustainability, since AoP are conceived as clearly dissociated and independent objects. We therefore discuss the choice of one theory (§ 7.5.1), then we set our work into the frame of the multiple capitals approach (§ 7.5.2.).

[39] i.e., private costs.

[40] An externality occurs when a decision within the value chain imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided by the value chain. Externalities are sometimes referred to as spillovers. An externality may also result in private costs, even though it might not be accounted for in the decision-making (UNEP/SETAC, 2009).

7.5.1. Choosing one theory for S-LCA

Starting from the economic theory, the concept of well-being puts its roots in the development theory. The concept of development has evolved in the last decades. Today, the idea of development includes well-being and quality of life. "In its most general acceptance, the term development can be seen as a synonym for that, in use since the Enlightenment, of "social progress" (or societal), in the sense that "the society of tomorrow may be better than that of today " (Coméliau, 2007).

The notion of development is not limited to the material dimensions of social progress: it questions the value systems, the diversity of the purposes of the human species, and the multiple means of their development (Coméliau, 2007). The notion of "good life" has thus interested the greatest philosophers. It is the subject of multiple definitions, covering a wide range of elements: sense of belonging and accomplishment, self-image, autonomy, feelings and attitudes of others, etc. However, none of these propositions is the subject of a universal consensus, each responding to a specific philosophical thought (Stiglitz et al., 2009). The challenge is not so much to precisely define these notions, but rather to know how to measure them rigorously.

There are three main theories of well-being in economic analysis. These are:

1) well-being defined as the satisfaction of preferences

2) well-being as happiness or satisfaction felt, and finally

3) well-being as conceived by the capabilities approach, developed by Sen (1977).

The first approach, called welfarism, consists in identifying the well-being of a person from a utility function representing the order of his preferences (Stiglitz et al., 2009). This approach is widely criticized as assessments based solely on the propensity to pay may disproportionately reflect the preferences of the better off to the detriment of the most disadvantaged. The second approach, subjective well-being, considers that it is the individuals who are best able to judge their own situation and therefore that well-being is equivalent to happiness or satisfaction felt. This evaluation based on experienced utility remains within the normative framework of welfarism. The third approach is part of a critique of the moral value of the usefulness of decision or experienced to make inter-individual comparisons of well-being (Tessier, 2009). Sen proposes to conceive individual well-being using the concepts of capability and function (Sen, 1999). The idea of Capability is based on the study of famines, poverty and inequality. In case of famine (Sen, 1981), the problem is not so much lack of food as is access to food. Sen considers that an individual holds endowment that he/she can convert, or from which he/she can produce a basket of goods, exchangeable for other baskets of goods with the rest of the community. These goods constitute the entitlements. In the starvation analysis, persons are hungry either because they do not have the ability to get food or because they do not use that capacity. Their trading rights card does not allow them to exchange their endowments for food (Bertin, 2005).

A person's Capability is therefore defined as the extent of the real possibilities to do and to be possessed by an individual. In force of all the explication above, we will concentrate on this third approach.

7.5.2. The Multi Capital Model (MCM)

The questioning about the principles on the basis of the old economy is at the origin of the extension of the concept of capital in economic theory (Feschet and Garrabé, 2013).

From the mid-1980s, many empirical studies were conducted to support the multi capital model. One considers a production function involving physical capital, human capital[41] (assimilated to skilled labour) and unskilled labour. Many work is developing on human capital.

MCM is a model of wealth creation with four capitals: economic capital, natural capital, social capital and human capital. The concept of institutional capital is still controversial, but always more recognized. In particular, human capital is made up of a set of human resources, accumulated and structured, including health (physical qualifications), knowledge (cognitive skills), skills (applied cognitive skills), and certain intellectual and non-cognitive social skills, such as various personal aptitudes (relationship skills and intellectual innovations) (Feschet and Garrabé, 2013).

Economic capital refers to resources that can be mobilized and produced during a production activity (economic or social, public or private). The goal is to have endowments to increase the capabilities of individuals, and - when realized - to improve well-being of people. These resources also shape (through human, social and institutional capital) the use function as defined by Sen, understood as a transformation vector (Figure 20). If, for example, an individual does

[41] It is also shown that human capital would have the same quantitative importance as physical capital to explain growth. Barro (1991) shows that another variable (the school enrolment rate in primary in 1960) would have a positive influence on growth. Associated with a colleague, they consider the effect of variables measuring the role of governments (Barro and Lee, 1993).

not have sufficient knowledge, he/she will not be able to transform his/her stock of economic endowments (land, seeds, etc.) in agricultural production activity.

The concept of capability is very much linked to human capital. Indeed, the mobilization of this form of capital requires the development of access capabilities. As we saw earlier, the basic capabilities (Sen, 1993) correspond to the fact that a person can perform certain basic acts, move, ensure the satisfaction of his nutritional needs and participate in the social life of the community. From this point of view, the capabilities constitute a stock of access capabilities.

The capability approach provides a framework for assessing individual situations. Social system and social organization are considered through their ability to promote human capabilities, but they are not considered as such. However, there are relations, social structures and/or institutional structures (e.g., corruption) that are harmful in terms of development and well-being.

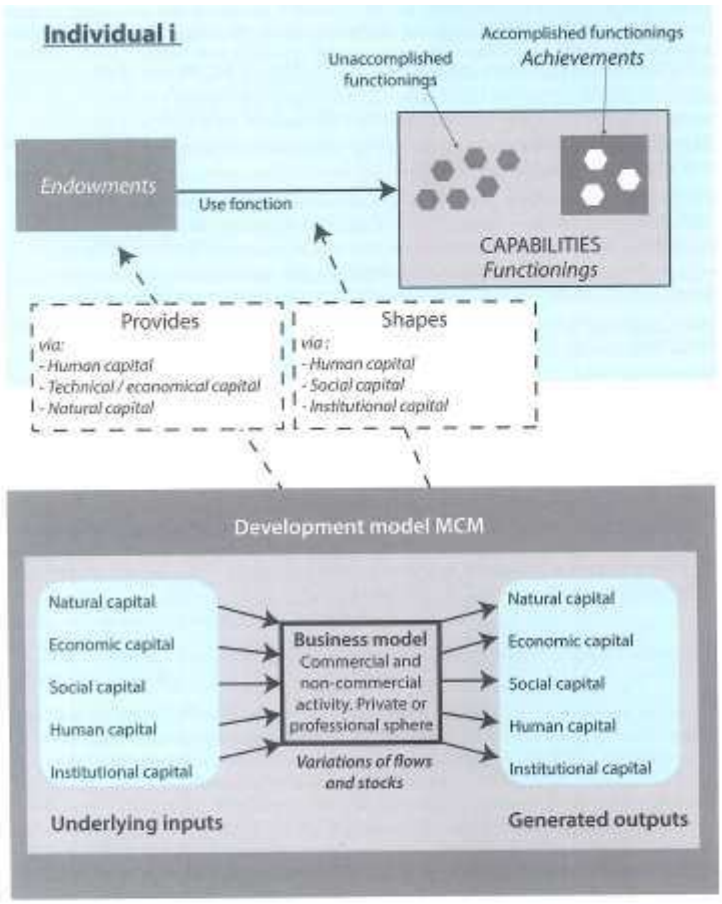

Figure 20 - Articulation of Capabilities approach and MCM (from Feschet and Garrabé, 2013)

7.5.3. Capacities S-LCA

S-LCA is a tool to assess social (and socio-economic) impacts of value-chains, the methodology of which is not yet stabilized. Guidelines of UNEP/SETAC (2009) have proposed a methodological framework, recognizing, however, that many issues remain unresolved.

From a methodological point of view, in Parent et al. (2010), two possible ways to carry out Impact Assessment (IA) are presented. These have been called Type I and Type II. Type I, or social life cycle attributes assessment (SLCAA) (Andrews et al., 2009; Norris, 2006), does not provide a quantitative measurement of social impacts for two reasons: it is in the sphere of the only internal corporate performance, and, therefore, offers the point of view of the producer of social actions; it depicts a static situation (so can't account for the impacts stemming from change). On the other side, Type II, or "pathways" analysis, looks for statistically significant relations between factors and impacts. Macombe (ed.) (2017; 2013). It has firstly been implemented by Norris (2006) in the second part of his paper, and Hutchins and Sutherland (2008) determining social impacts on human health resulting from a change in products' life cycles (Neugebauer, 2016). Within this type II, Garrabé and Feschet (2013) specify an approach called "Capacities social LCA", which is rooted in the Sen's theory of Capabilities. The type II impact assessment consists of two phases: in the first one, an empirical correlation between two parameters of interest is established, e.g. between income inequality and human health (see e.g., Bocoum et al. (2015)) (Figure 21); in the second one, a potential social impact is predicted resulting from a change in a product´s life cycle (microeconomic level) that affects an indicator of social sustainability (whatever the scale, such as population human health or social climate in a workshop), based on the earlier determined empirical correlation.

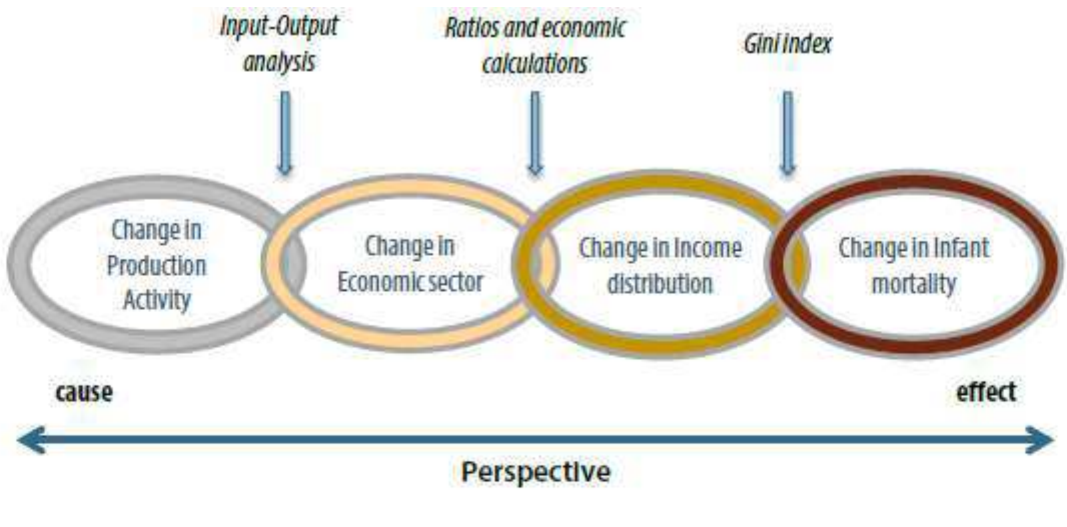

Figure 21 - Illustration of the Wilkinson pathway (from Bocoum et al., 2015)

Focusing on the Capacities LCA approach, the principle of the Capacities S-LCA is to articulate a chain analysis with an MCM approach retaining only five of the anticipated classes of capital to the exclusion of the natural capital, in order to measure the variations of capacities of the actors, resulting from the social practices of companies (Figure 2). The point is not to measure a behavioural performance of social responsibility, but to measure an impact on the actual potential capacities, even on the real capacities of the actors.

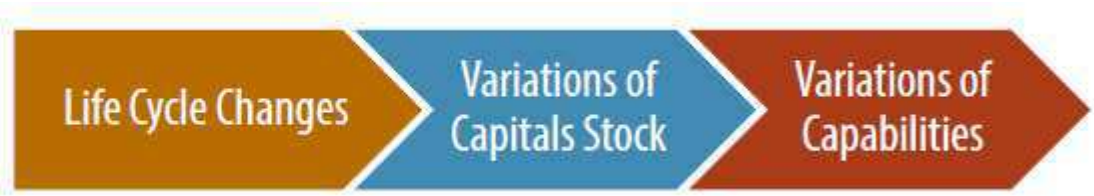

Figure 22 - Example of capacities and capabilities approach (from Iofrida, 2017)

This research work contributes to the study of the way in which human capital (considered like an input in the MCM approach) could be consummate to reach determined results in terms of export market (in our case) (Figure 3).

Figure 23 - This research work following Capabilities approach

7.5.4. Capacities S-LCA: practical implementation

From a practical point of view, Garrabé and Feschet (2013) proposed an eight-phases implementation. We will detail them in the following paragraphs making also the link with the present research work.

1. Identification of classes and sub-categories of capitals (SCC)

In this phase, the practitioner proceeds to the identification of the five types of capital (i.e., human, technical, financial, social and institutional). Then, he/she identifies capital sub-categories. As stated above, in this work we focus on human capital. Consequently, in Figure 4 we report the human capital sub-categories only.

CAPITAL CATEGORIES	CAPITAL SUB-CATEGORIES	
HUMAN CAPITAL	1	Education
	2	Working conditions
	3	Health
	4	Security
	5	Parity

Figure 24 - Human capital sub-categories (adapted from Garrabé and Feschet, 2013)

2. Identification of classes of potential capacities effects (CPCE)

For each sub-category selected, Categories of Potential Effects of Capacity are identified. Figure 25 shows the CPCE for "human capital".

In the theoretical elaboration of the "human impact" we took into account the following capital sub-categories, with the connected CPCE:

- Education. Between the "PPE policies" we investigated if farmworkers receive training about pesticide-related risks, PPE wearing and good practices regarding pesticide manipulation.
- Working conditions. The main aim of this research work is to provide a tool to guide the conceptualization of innovative cropping systems less risky regarding working conditions (in particular, relative to CPCE 2.4, 2.8.). Otherwise, we affect, during the entire thesis, also other CPCE (e.g., working time, employment contract).
- Health. Strictly connected to the previous sub-category, we focused on effects due to pesticide exposure, e.g., reduction of life expectancy and suffering from occupational diseases. Moreover, the presence of "PPE policies" affects the CPCE 3.3.
- Security. In our case study observation, we marginally reported about these themes (4), highlighting the matter of Haitian immigrants in Dominican Republic and the connected problems of housing, rights, etc.
- Parity. During the interviews we conducted and the relative discussion, we dealt with questions linked to discrimination (e.g., presence, or not, of women in plantations;

different roles assigned to Haitian and Dominican workers). Nevertheless, this particular aspect is not nested in the indicator.

HUMAN CAPITAL SUB-CATEGORY		CATEGORIES OF POTENTIAL EFFECTS OF CAPACITY (CPEC)	
1	Education	1.1	To receive Training (M-W)
		1.2	To receive an internal qualifying training (M-W)
		1.3	To receive a qualifying and graduate training (M-W)
2	Working conditions	2.1	To have a normal working time (days, weeks, …) (M-W)
		2.2	Have breaks in their work (M-W)
		2.3	Do not suffer at work (M-W)
		2.4	Do not bear risks at work (M-W)
		2.5	To have an employment contract (M-W)
		2.6	Do not work before the legal age (M-W)
		2.7	To receive a regular salary (local & industry standards) (M-W)
		2.8	Do not be forced into illegal labor practices (M-W)
		2.9	To be respected in the workplace (M-W)
3	Health	3.1	Do not have a reduced life expectancy (M-W)
		3.2	Do not suffer from occupational diseases (M-W)
		3.3	To be subject to preventive measures (M-W)
		3.4	To have care if necessary (M-W)
		3.5	To eat in suitable conditions (M-W)
4	Security	4.1	To have insurance at work (M-W)
		4.2	To have housing for migrant workers
		4.3	To be lawfully in the territory
		4.4	To have the protection of every citizen
5	Parity	5.1	Not be discriminated against as a woman
		5.2	Not be discriminated against as an older worker
		2.3	Not be discriminated against as a foreign
		5.4	Not be discriminated against for political reasons
		5.5	Not be discriminated for religious reasons

Figure 25 - Classes of Potential capacities effects (from Garrabé and Feschet, 2013)

3. Identification and collection of internal information

In general, it is possible to relate Indicators of Potential Capacity Conditions (ICEPC) to each class of potential capacity effects, to identify the forms of action chosen by the company. We carry out this identification during the case study, investigating the policy and the choices made by different plantation managers.

4. Identification and collection of external information

The information collected by survey in the company makes possible the identification of the actions carried out but not of the impact of these actions. The way in which these actions are concretely translated in terms of impacts would imply multiple detailed surveys of the various actors who are the subjects. Faced with the difficulty of carrying out all these investigations, one relies to:

- additional ad hoc surveys;
- available external studies (local or transferable data);
- as well as expert interviews. The use of expertise may be necessary both in the collection of information and the interpretation of consequences.

We carried out interviews of experts as a basis for our work, collecting information about plantation real practices, but also regarding the potential risks to whom operators are exposed.

5. Diagnostic of variations of potential capacities effects

In this phase, the practitioner identifies an increase or decrease of potential capacity effects (PCEs) by level of indicator. This process includes: validation of the collected external information; cross-checking with company survey; and interpretation.

6. Estimation of variations of potential effective capacities effects, and
7. Passage from potential capacities effects to real effects.

The results of the "human impact" indicator represents an estimation of the negative variation of the capacity of the human capital linked to different management practices, and technical practices carried out in plantations. It can' be interpreted alone, and must be interpreted in comparison.

7.5.5. *The Wesseling pathway*

As reported by Macombe (2017), the principal usages of S-LCA are:

• providing knowledge about some likely main consequences of the change (what are the likely main impacts in terms of public health and in terms of involved workers' health);

• helping for coordination of actors (for instance, as a basis for discussions of the configuration of the project);

• influencing decision about future projects. The studies stemming from S-LCA highlight the main social issues, and claims for changes in the present project which may be marginal from the technical point of view, but very important from the social scope;

• helping to fine-tune the social side of projects. S-LCA fills in the social side of projects, by reporting on several social aspects (expected and unexpected), and by claiming for modifications when necessary;

• generating innovations driven by social considerations (e.g. mitigating health impacts of pesticides use, like in this specific work).

Between 2005 and 2008, the World Health Organization decided to set up a "Commission of Social determinants of Health" (CSDH), in charge of explaining the relationships between health of population/households and many other factors (e.g. land rights, decent work, bribery etc.). The purpose was to officially acknowledge the links between relevant social conditions and health, in order to advise policy makers for sound (inter sectoral) policies for health.

In the report of the CSDH (WHO, 2009), the authors have split the social determinants into two scales:

- the "macro" scale of one state, or large region, in developing countries,
- the "meso" scale of a group of rural households, in rural regions of developing countries (depicted in Figure 26).

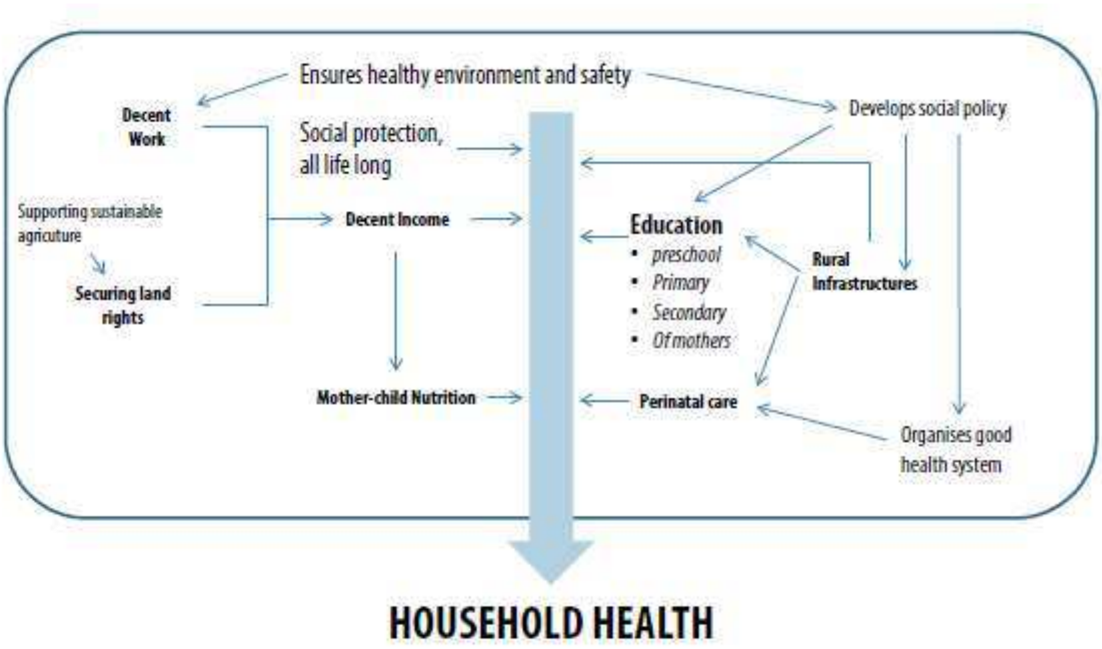

Figure 26 - Diagram of flows at meso-scale (from Loeillet and Macombe, 2017)

The present work is part of the diagram depicted above, aiming encouraging decent work through identification of possible choices less harmful to health, and ensuring healthy environment and safety. The result of this entire thesis work is formalized in a meso-scale pathway, named "Wesseling pathway"[42] (Figure 27).

Figure 27 - The Wesseling pathway

This pathway can be detailed as in Figure 28, where it is represented the cause-effect chain between cropping operations and acute toxicity. This one can be represented as divided into three parts:

[42] We named this pathway from the name of Dr. Catherina Wesseling (see Wesseling et al., 1993) who spent her life to investigate health damage because of pesticides, with special attention paid to workers in banana plantation in Costa Rica.

1. Planning. In this phase the decision maker (e.g., plantation manager, consultant) decide what production steps have to be carried out in order to obtain the desired agricultural product (e.g., a product with: a requested set calibre, particular physical characteristics, with no birthmark of pest presence). In function of the desired product, he/she set also the sub-steps and the actions and the manner to carry out these in terms of:
   a. Necessity, or not, of pesticide application.
   b. Type of product (chemical, or not) that have to be applied.
   c. Number of application repetition (this number can be modified in reason of unexpected events, like unusual meteorological conditions.
   d. Determination, or not, of preparation conditions in terms of: tools to be used in the mixture preparation (e.g., mixing tanks), place in which the preparation have to take place, who is appointed to carry out this task.
   e. Determination of application conditions, in terms of: particular tools to be used in the pesticide application (e.g., plane, quad, backpack sprayer), who is appointed to carry out this task. In this part, the decision maker can also plan the work organization in the plantation (e.g., creation of application teams of workers entirely, or mainly, devoted to pesticide application).
   f. Determination of instrument cleaning conditions, in terms of: tools to be used in the cleaning task (e.g., particular tools), place in which the cleaning has to take place, who is appointed to carry out this task.
2. Implementation. In this second phase there is the factual carrying out of the different tasks. It is in this phase that the adverse conditions (e.g., heat, humidity, slope) may affect what was prescribed in the first phase. In the implementation phase we observe also the use, or not, of PPE and, more in general, of bad practices.
3. Consequences. In this phase we observe the related exposure, and the consequences in terms of acute toxicity. We highlight as this is the only phase in which the decision maker has no power of intervention.

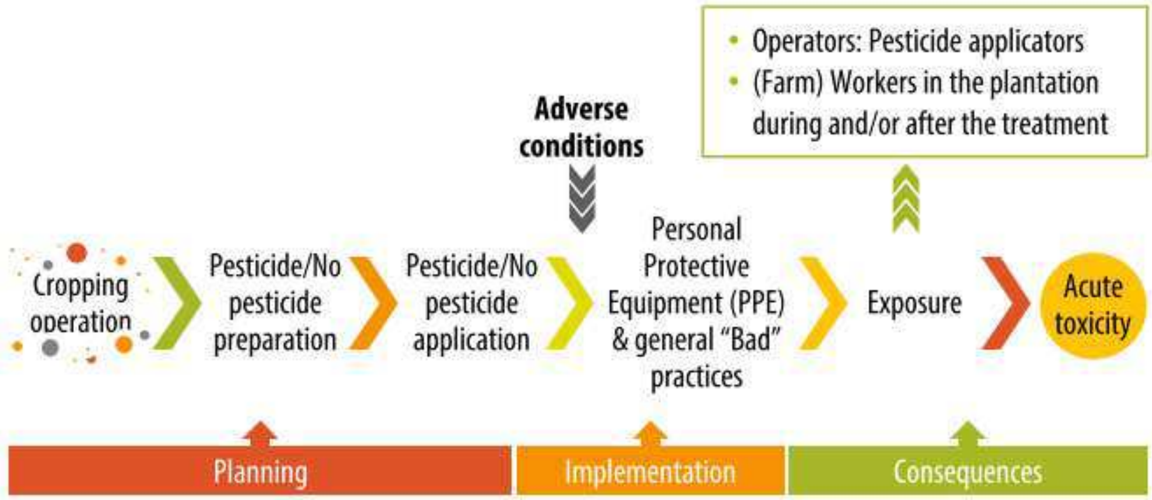

Figure 18 - Detailed relation between cropping operation and acute toxicity based on real practice implemented

Chapter 8: Conclusions

After summing-up the thesis arguments (§ 8.1), we envision avenues for future work (§ 8.2).

8.1. Wrap-up

In this paragraph we will summarize the research work presented in this thesis.

8.1.1. Constraints of the assessment of pesticides health risk

Assessing the magnitude of health risks from pesticide exposures in the workplace is of the utmost interest. Nevertheless, it is difficult to do for many reasons. Exposures are usually intermittent and pesticide metabolites have a short half-life. Nonetheless, available scientific evidence strongly suggests that pesticides cause cancer and other health damages in both people who use the pesticides directly and people who are exposed because of applications made by others. The problem may well be more extreme in developing countries because regulatory controls are weaker or non- existent, and because safe methods of handling pesticides and safety practices are often lacking.

In this field, the aim of this PhD thesis was to develop a decision support tool aiming at classifying by anticipation different cropping systems, regarding their impact on farmworkers health. The generic tool would be applicable on the agricultural phase of the life cycle of any agricultural product. To date, we developed only one specific tool for banana plantations. Here we expose results about operators' (workers directly using pesticides) health only.

8.1.2. Links between cropping systems, pesticides and Human Health

Damages to operators' health caused by pesticides use are modulated and influenced by many different factors, which can be roughly depicted in Figure 29. To comply with country or market regulations, or because of new company policies (e.g. due to environmental/social labels) or cost reduction, variations can occur in the chain leading to damaging operator's health

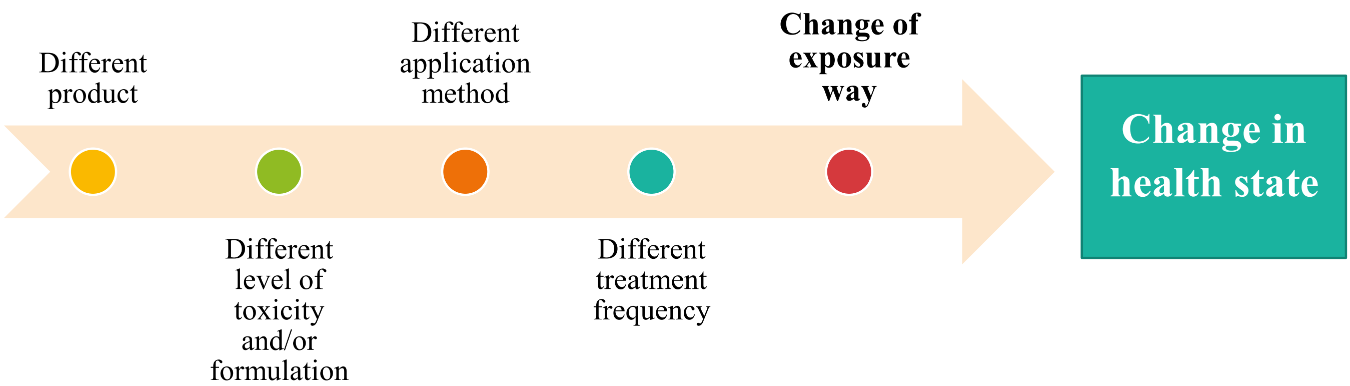

Figure 29 - The change in damage to operator's health because of pesticides can have many causes

Consequently, the damage caused by pesticides to one operator's health can be modulated by:

- different levels of toxicity;
- different formulations, which may change the way of exposure (e.g. if one switches from liquid to powder, the exposure can evolve from a principal dermal exposure to a principal inhaling exposure);
- different application methods (when changing from aerial to terrestrial application, the level of exposure changes too);
- different treatment frequency. The more the treatment is frequent, the more the operator is liable to be exposed;
- different changes of exposure way (for instance from inhaling exposure to dermal exposure, with different quantities);

If methods are able to discriminate cropping systems according to these different criteria, they are able to account for damage to operator's health because of pesticides.

8.1.3. Current methods to discriminate cropping systems thanks to assessment of pesticides impact

A literature analysis highlights that the current methods to discriminate cropping systems on the base of their impacts dues to pesticides, can be sorted out between two principal groups:

- Environmental-Life Cycle Impact Assessment (E-LCIA) methods,
- Risk Assessment (RA) methods.

In synthesis, regarding the damages caused by pesticides use to operators' health, Risk Assessment focus to different level of toxicity and/or different formulations, while E-LCIA focus on the assessment of different quantities of spread pesticides.

We therefore seek to complement these approaches by creating the "Wesseling pathway", whose aim is to assess the change in the operator's exposure way, due to changes in the previously mentioned variables (Figure 30).

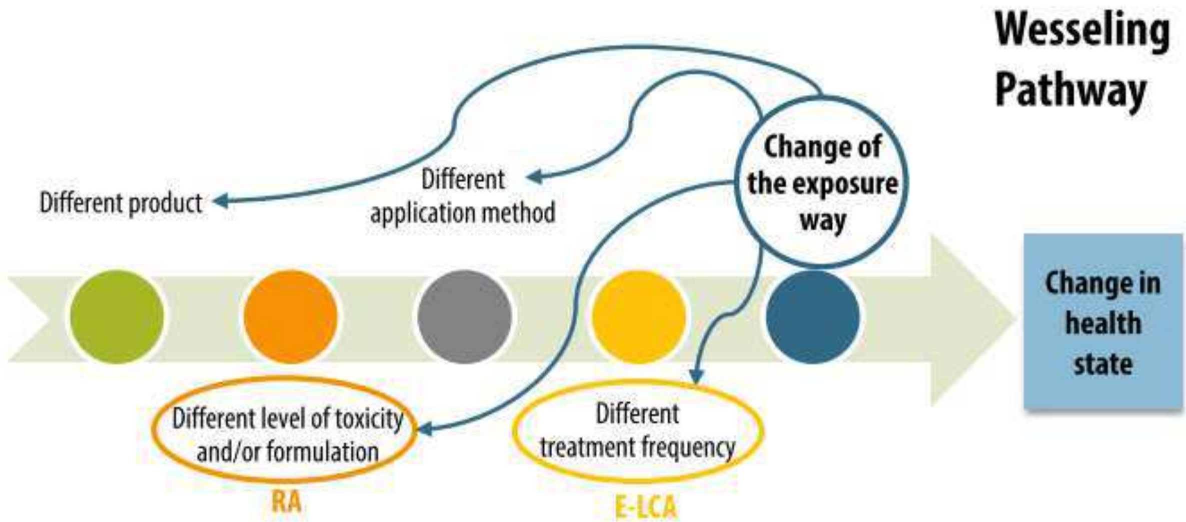

Figure 30 - Different methods address different factors

8.1.4. The Wesseling pathway

Since the current methods do not allow considering the actual practices on the ground, we propose a model that considers practices, and which is usable to anticipate future impacts.

We took as object of study the case of banana farmed to exportation. Banana is the most commercialized fruit in the world. Moreover, the economies of several developing countries are dependent from this crop.

We based our work on experts (of banana plantations) elicitation. Indeed, to date, it is the only one way to account for the real practices on the ground. Expert elicitation refers to a systematic approach to synthesize subjective judgments of experts about one issue, when there is uncertainty due to insufficient data, or when such data are unattainable because of physical constraints or lack of resources

We applied expert elicitation through a Delphi expert consensus method. The collected interviews testify that – under some particular working conditions (e.g. heat and humidity) –

the exposure risk becomes very high, because the use of personal protective equipment (PPE) is thwarted by the working conditions.

From the interviews, we designed knowledge trees. The aim was creating several cause/effect chains (one is detailed in Figure 28) relating each cropping action that entails use of chemicals (mainly pesticides and fertilizers) to the potential health damage caused by acute toxicity.

Exposure can occur through the preparation and application techniques of chemicals (e.g. pesticides), or during the cleaning step.

Thanks to the experts' interviews, we were able to relate the different situations with application techniques, and workers behaviours concerning PPE when they practice pesticide application. All these practices impact on the health of three populations at least: operators, farmworkers working in the plantation during the treatment, and farmworkers entering the field after the treatment.

8.1.5. "Human impact of pesticides" indicators

Starting from the knowledge trees, we built "human impact " indicator for the operators. The main contribution of experts is providing the wj (degree of operators' exposure) terms for diverse conditions. The general indicator allowing to calculate the average human impact of pesticides for operators for one cropping action is depicted in Equation 56 (§ 4.1.5):

The calculation of pesticide human impact can be achieved following temporal and spatial aggregations of several "costs of one cropping action":

- for the entire lifespan of a plantation (5-30 years);
- for the cycle corresponding to a single crop (9 months to 12 months in routine);
- for all transactions for a year on a routine plantation (about 52 crops per year);
- per parcel, per hectare, or per any area of the plantation.

Interpretation of the results of pesticide human impact calculations should be done only by comparing at least two scenarios implemented with the same temporal and spatial scales. Indeed, the result of a calculation alone is meaningless in the absolute.

8.2.Future perspectives

Recalling what we specified in § 7.1, the work presented in this PhD thesis could be improved through future developments.

Firstly, a future conceptualization will regard multi exposure to pesticides, both in the sense of repetitions in the time, and in the sense of exposure to multiple chemicals along the same exposure and/or working life.

To provide a more complete evaluation of "human impact" of pesticide use, two actions have to be carried out: first, the development of a "human impact" indicator for generic farmworkers. In this way a more complete evaluation of risks connected to pesticides use in plantation could be provided. To this aim, the authors propose, in Annex 9, a possible formalisation of knowledge trees for generic farmworkers.

In a broad sense, the same work structure could be adopted to build a "human impact" indicator for other life cycle stages (e.g., transportation, selling) to get a more synthetic and significant position of our "*filière*" as a whole related to other ones.

The indicator structure could be refined in order to consider also non-linear relations between exposure and disease.

In a wider perspective, the indicator here developed could potentially be adjusted to other crops. This implies an important work in adapting to different countries, that, generally, had different peculiarities linked to different crops, different culture, different economic background, and different regulations about pesticide use.

After these, we suggest establishing a case study of comparison between conventional and "social labelled" productions (e.g., Fair Trade). In fact, a real amelioration of workers conditions is not always the case[43].

The authors want also to encourage the use of participative approaches in conceptualizing innovative cropping systems, in order to be able to devise initiatives and measures answering to context necessities with major chances to be implemented by workers and residents.

[43] For a specific example on Dominican Republic banana's production, please see: https://www.theguardian.com/environment/2012/may/28/fair-trade-food .

The same initiative should be taken also in S-LCA context, in order to involve actors in the definition of either the types of relevant impacts, or, more in general, the Impact Assessment methodology[44].

Sorting from the methodological field, it remains the necessity to reduce diseases due to pesticide exposure. The long-term solution to pesticide problems is education. Who bears the responsibility of training these people remaining on the farms, who now shoulder the challenge to increase greater production of food? Government's departments responsible for pesticides have too few trained agronomists, chemists, biologists, engineers, etc., in extension service roles at the local level. They have to gather and analyse samples (water, soil, product), to advise farmers, to educate and work with people using pesticides or to initiate and promote new agricultural and integrated pest management practices, in addition to personal and family protection programs. Effective information transfer is the key to reducing many of the pesticide-related problems (Ecobichon, 2001).

In conclusion, the authors want to emphasize that, sin parallel with education policies addressed to agricultural population and, more generally, to those who come into contact with chemical products, one should undertake education policies to consumers themselves. It would create a greater awareness of the rhythms and limits of nature itself, and, last but not least, of the true meaning that labels of an environmental and social nature actually have in the agricultural field.

[44] For more information, seeMathe (2014); Di Cesare and Mathe (2017).

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Thesis abstract in English

Ecosystems and people are exposed every day to multiple chemical stressors via multiple pathways and routes due to economic and population growth. Considering that the use of pesticides is especially prone to potentially damage health in the workplace, we decided to design a dedicated method. This thesis project aims to develop a method to examine the comparative effects of different agricultural production systems on operators' health because of pesticide. The objective is to enable the assessment of a comprehensive set of information for decision support purposes, considering the actual (good and bad) work practices. Furthermore, a decision support tool for different stakeholders (plantation managers at first) to discriminate between several production systems regarding their potential impact on farmworkers health, is under development. This method has to be based on readily available data in a reasonable time, and corresponding to meaningful data for managers, to provide them opportunities of action in crop innovation. We followed four steps: seeking help of experts; constructing knowledge trees; developing decision trees; calculating the potential impact on farmworkers health due to pesticides for operators at different scales, and regarding one given farming system in a feasibility test. The first phases were implemented through a Delphi expert consensus method eliciting knowledge from agronomists, economists and exposure assessment specialists, in order to map the different "banana workflows" and the origins of good and bad practices. After getting and interpreting results of the indicator calculation in the feasibility test, we ought to propose improvements of the method. We decided to carry out a feasibility test through semi-structured interviews. We flank these interviews with direct observation of operators and workers accomplishing the different steps of the production. The aim of this comparison is to cross- check both what experts referred in their narration (information present in trees), and what the interviewed persons declared. Conventional (non-organic) producers were selected for interviews. This research work contributes to the study of the way in which human capital (considered like an input in the MCM approach) could be consummate to reach determined results in terms of export market. The present work aims encouraging decent work through identification of possible choices less harmful to health and ensuring healthy environment and safety. The result of this entire thesis work is formalized in a meso-scale pathway, named "Wesseling pathway".

Thesis abstract in French

Les écosystèmes et les personnes sont exposés chaque jour à de multiples facteurs de stress chimiques par l'intermédiaire de multiples voies et voies en raison de la croissance économique et démographique. Considérant que l'utilisation de pesticides est particulièrement susceptible de nuire à la santé sur le lieu de travail, nous avons décidé de concevoir une méthode dédiée. Ce projet de thèse vise à développer une méthode pour examiner les effets comparatifs de différents systèmes de production agricole sur la santé des opérateurs à cause des pesticides. L'objectif est de permettre l'évaluation d'un ensemble complet d'informations à des fins d'aide à la décision, en tenant compte des bonnes et mauvaises pratiques de travail réelles. En outre, un outil d'aide à la décision pour les différentes parties prenantes (les gestionnaires de plantations dans un premier temps) pour faire la différence entre plusieurs systèmes de production concernant leur impact potentiel sur la santé des travailleurs agricoles, est en cours de développement. Cette méthode doit être basée sur des données facilement disponibles dans un délai raisonnable, et correspondant à des données significatives pour les gestionnaires, afin de leur fournir des occasions d'action dans l'innovation des cultures. Nous avons suivi quatre étapes : demander l'aide d'experts ; construire des arbres de connaissances ; développer des arbres de décision ; calculer l'impact potentiel sur la santé des travailleurs agricoles dû aux pesticides pour les opérateurs à différentes échelles, et concernant un système agricole donné dans un test de faisabilité. Les premières phases ont été mises en œuvre grâce à la Delphi experts consensus method qui a permis d'obtenir des connaissances d'agronomes, d'économistes et de spécialistes de l'évaluation des expositions afin de cartographier les différents flux de production et les origines des bonnes et mauvaises pratiques. Après avoir obtenu et interprété les résultats du calcul de l'indicateur dans le test de faisabilité, nous devrions proposer des améliorations de la méthode. Nous avons décidé de réaliser un test de faisabilité à travers des entretiens semi-structurés. Nous flanquons ces entretiens avec l'observation directe des opérateurs et des

travailleurs accomplissant les différentes étapes de la production. Le but de cette comparaison est de vérifier à la fois ce que les experts ont référé dans leur narration (informations présentes dans les arbres) et ce que les personnes interrogées ont déclaré. Les producteurs conventionnels (non biologiques) ont été sélectionnés pour des entrevues. Ce travail de recherche contribue à l'étude de la manière dont le capital humain (considéré comme une entrée dans l'approche MCM) pourrait être consommée pour atteindre des résultats déterminés en termes de marché d'exportation. Le présent travail vise à encourager le travail décent en identifiant des choix possibles moins nocifs pour la santé et en garantissant un environnement et une sécurité sains. Le résultat de l'ensemble de ce travail de thèse est formalisé dans une voie méso-échelle, appelée « Wesseling pathway ».

Annex 1 - Redesign banana cropping systems in tropical areas

Guadeloupe and Martinique are island environments where pollution problems from pesticides arise with particular acuity. These areas have been heavily impacted by the pollution of the soil by the chlordecone (or kepone), an insecticide used against weevils in banana plantations.

Since the 1990s there has been a shift in cultivation techniques with the gradual abandonment of monoculture systems from high consumption of chemical inputs, in favour of systems based on cleansing practices combining: healthy plant material from in vitro cultures, fallow and crop rotations. These systems have proved effective in limiting the pressure of telluric pathogens without the use of nematicides, contributing to the restoration of soil fertility. This has already led to a reduction in the use of nematicides of more than 65% in the plantations of Martinique. Similarly, the weed control is implemented by using mulching or the use of cover plants.

There are scientific and technical basis necessary for the identification of alternative farming techniques to the use of pesticides. We must, however, incorporate these cultural practices within the new culture systems, evaluate them and ensure their adoption capacity.

Here below a schematic detail of the main banana's diseases and of possible solutions.

Black/Yellow Sigatoka

The Black/Yellow Sigatoka can difficultly be managed using only the cultural control practices (e.g., partial or total necrotic leaf removal, suppression of infectious outbreaks). The obtaining of resistant cultivars is the main objective of the genetic improvement programme lead by CIRAD (Bakry et al. 2001).

Tixier et al. (2010) evaluated the link between silicon availability for plants and the presence of pests. Kablan et al. (2010) and Vermeire et al. (2011) showed as the pests impacts decrease if the silicon nutrition is better. This latter can be improved through a soil amendment rich in silicon (e.g., sugar cane bagasse).

Preventive Practices to limit fungal population

- Cut of all the leaves on the mother plant during harvest.
- Reduce humidity in the plots through a proper management of irrigation and drainage (drip or under foliage spray are less favourable to the development of the fungus than overhead sprinklers).
- Weeding, up to date de-suckering, a planting density of 1650-1850 plants/ha, and maintenance of edges, will allow good aeration of the plot.
- Rapid destruction of all fallow plots to avoid creating infestation reserves. Elimination of all isolated bananas found at the edge of the plots, in the gullies, etc.
- Regular and balanced fertilization.

Curative practices to eliminate fungal population

When only Yellow Sigatoka is present, proceed to a regular trimming (weekly) focused on the necrotic parts when they represent less than 20% of leaf surface, beyond this, and remove the entire leaf. For Black Sigatoka, cut the entire leaf with necrosis, regardless of the level of infestation.

Organic products

The *"Institut Technique Tropical"* (IT²) is working on the possibility of using biological preparations (e.g., yeast, vegetable oils and stimulators of natural defence systems) in addition to chemical control to limit the emergence of resistance. The objective is to reduce the use of chemicals by including biological preparations in an integrated treatment program.

Weeds

Weeds have their great development in the plantation installation phase.

In addition to the management of crop residues and mechanical means, the use of cover crops (Damour et al. 2012) is the most appropriate option for the control of weeds.

Banana weevils

The nematodes were controlled through implementation of control measures consisting in crop rotation, fallowing and the use of plants from in vitro culture (Chabrier et al. 2005; Chabrier and Quénéhervé 2003; Ternisien 1989). These measures, used on a large scale, have reduced the use of nematicides.

The development of attractive pheromone traps allows controlling populations (Chabrier et al. 2002), but, to maximise the efficacy, their distribution in space and time have to be optimised.

It is necessary also to develop cultural practices to incentive biological regularisation of insects by culture auxiliaries (e.g., Tixier et al. 2010).

Monitoring of a regular array of pheromones traps has shown that the fallow played a preponderant role in the epidemiology of the pest to the scale of group of plots and entire farm (Rhino et al. 2010). In fact, fallows can clean up the farm plot abolishing resources useful for weevil survival.

Duyck et al. (2011) highlight also that the use of cover crops can increase the weevil control due to a modification of its diet.

Annex 2 - Questionnaire prepared to be given to plantation managers (English version)

Introduction

1. What is your role in the plantation?
2. What is the corporate owner of the plantation?
    a. Does it have an email address?
3. What is the plantation name?
4. Where this plantation is located?
5. How many years has this plantation?
6. Do you know what was the production of this plantation in 2015/2016?
7. What is the plantation extension (*tareas*/ha)?
8. How many workers are currently working in this plantation?

Plantation particulars

1. Who is the owner of this plot of land?
2. In this plot of land, do you produce only bananas?
    a. If not, what are banana's co-products?
3. Which territorial extension is dedicated to banana cultivation?
4. Which territorial extension is dedicated to co-products?
5. In this plantation, do you produce bananas for export?
    a. If yes, which percentage of total banana production is destined to export?
6. In the context of pesticides application activity, are they used service providers?
    a. If yes, in which plantation phase?
    b. If yes, how many they are?
    c. If yes, what is the firm name?
7. In the context of pesticides application activity, are they used internal "phyto" teams?
    a. If yes, in which plantation phase?
    b. If yes, how many they are?
8. To incentive operators wearing Personal Protective Equipment (PPE), are trainings on pests' harmfulness and/or pests linked diseases organized?
9. To incentive operators wearing Personal Protective Equipment (PPE), are bonus (cash) payments provided?
10. The producers' association will provide services for plant health activities?
    a. If yes, what services (e.g., training, collective pesticides buying, etc.) are provided?

Tasks evaluation

1. What of the plantation steps listed below are implemented in a single crop?

    ☐ Destruction of the old plantation

    ☐ Fallowing

    ☐Nursery

    ☐Nursery (shadehouse)

    ☐Fertilization

    ☐Weeding

    ☐Plant protection (Black Sigatoka and weevils)

    ☐Bunch care

    ☐Post-harvest treatments (in the packaging plant).

    ☐Others: ____

2. What are the methods of preparation of the mixture?
3. What are the adopted methods to apply different pesticides?

Cleaning instruments

1. In the work organization, there is an instrument cleaning phase?
    a. If yes, with what frequency is carried out?
    b. If yes, by whom has done?
    c. If yes, which substances are used?
    d. If yes, in what place occur?
    e. If yes, are waste water management processes implemented?

Annex 3 - Questionnaire prepared to be given to plantation managers (Spanish version)

Introducción

1. ¿Cuál es su rol en la plantación?
2. ¿Quién es el dueño de la plantación? (¿persona moral o empresa privada?)
   a. ¿Tiene un email?
3. ¿Nombre de la plantación?
4. ¿Dónde se sitúa la plantación?
5. ¿Qué edad tiene la plantación?
6. ¿De cuánto fue la producción de esta plantación en 2016?
7. ¿Superficie de la plantación? (tareas)
8. ¿Cuántos trabajadores trabajan en la plantación (temporales, permanentes)?
9. ¿Pertenece a una asociación de productores? Si **sí**, ¿a cuál?

Detalles sobre la plantación

1. ¿Quién es el dueño de la finca? (¿privado, estado?)
2. En esta finca, ¿se produce sólo banano?
   a. Si **no**, ¿cuáles son los otros cultivos?
3. ¿Cuál es la superficie dedicada al cultivo del banano?
4. ¿Cuál es la superficie dedicada a los otros cultivos?
5. En esta plantación, ¿produce banano para la exportación?
   a. Si **sí**, ¿qué porcentaje del total de banano producido se destina a la exportación?
6. Para la aplicación de pesticidas, ¿recurren a empresas externas proveedoras de servicios?
   a. Si **sí**, ¿para qué actividad específica? (Sigatoka, otras)
   b. Si **sí**, ¿cuántas veces por actividad?
   c. Si **sí**, ¿cuál es el nombre de la empresa?
7. Para la aplicación de pesticidas, ¿dispone de un "equipo" especial encargado de aplicarlos, o cualquier obrero lo hace?
   a. Si **sí**, ¿para qué actividad específica? (Sigatoka, otras)
   b. Si **sí**, ¿cuántos son?
8. ¿Qué "Equipo de Protección Individual" utilizan (botas, trajes, lentes, etc.)?
9. ¿Dispone de un local especial donde se almacenan los productos fitosanitarios?
10. ¿Tiene un local donde guarda los "Equipos de Protección Individual" nuevos?
11. ¿ Tiene un local donde guarda la ropa limpia de los obreros, que no son los Equipos de Protección?
12. ¿Qué hacen con los Equipos de Protección Individual ya usados? (basura, reutilizan, donde los guardan)?
13. Para incentivar a los operarios a utilizar el "Equipo de Protección Individual", ¿se organizan formaciones sobre los riesgos del uso de pesticidas o enfermedades vinculadas al uso de pesticidas?
    a. Si **sí**, ¿Con qué frecuencia?
14. Para incentivar a los operarios a utilizar el "Equipo de Protección Individual", ¿se otorgan primas (efectivo) o algún otro tipo de bonificación?
15. ¿Realizan formaciones sobre gestos técnicos para la protección de las plantas (¿deshoje, etc.?)
16. ¿La asociación de productores provee servicios entorno a al manejo de las plagas y enfermedades de las plantas?
    a. Si **sí**, ¿qué servicios provee? (ej. Capacitación, compras conjuntas, etc.)

Evaluación de las actividades

1. ¿Cuáles las etapas siguientes realiza en su plantación?

☐ Destrucción de la antigua plantación: ¿cómo? ¿Con qué? ¿Cuánto tiempo?

☐ Barbecho: ¿cómo? ¿Cuánto tiempo?

☐ ¿Dispone de un vivero para la fase de aclimatación?

☐ ¿Dispone de un vivero para la fase de endurecimiento?

☐Fertilización: ¿cómo? ¿Con qué productos? ¿Cantidades? ¿Cuántas veces al año? Fertirrigación? ¿Mineral? ¿Orgánico? ¿Foliar?

☐Control de malezas: si, no? ¿Mecánico? Herbicidas? ¿Cuáles? ¿Cuantas veces al año? ¿Cantidades?

☐Control de la Sigatoka: ¿cuantas veces al año, qué productos, cantidades?

☐Control de otras plagas y enfermedades: ¿cuáles? (picudo, nematodos, trips, otros?). ¿Cómo trata, ¿con qué?, ¿cuántas veces al año?

☐Protección del racimo: ¿bolsas impregnadas o no? ¿Otra cosa para proteger a los racimos?

☐Tratamientos poscosecha (en la empacadora). ¿qué tratamientos? Fungicidas? ¿Cómo los aplican (pincel, túnel, pulverización)?

☐¿Algo más que hayamos olvidado?: ____

2. ¿Cuáles son los métodos de preparación de las mezclas de productos?
3. ¿Qué métodos se usan para aplicar los diferentes productos?

Limpieza de los instrumentos

1. En la organización del trabajo, ¿existe una etapa de limpieza de los instrumentos?
   a. Si sí, ¿con qué frecuencia se lleva a cabo?
   b. Si sí, ¿quién lo realiza?
   c. Si sí, ¿en qué lugar?

d. Si sí, ¿tiene un proceso de gestión/reciclaje del agua usada?

Pregunta para los trabajadores

1. Nivel de alfabetización
2. ¿Utiliza el "Equipo de protección Individual"?
   a. Si **no**, ¿por qué? (indisponibilidad, incomodidad: calor, humedad)
3. ¿Cuántas horas al día trabaja?
4. Cuando se realiza un tratamiento fitosanitario en una parcela, ¿sale usted de la parcela?
5. ¿Luego de cuánto tiempo vuelve a entrar a la parcela?

Annex 4 – Interviews' transcription

Introduction

The plantations are located in Atillo Palma (I1 and I2), and Boca de Mao (I3 and I4).

I1 reports they own the plantation since 1998. A part was renewed 10 years ago, and they started renewing a portion in May 2016. I2 reports they own the plantation since 2012, but it exists since before. They have an area with 4 years and another area that they estimate of about 20 years. 60% of the surfaces are old (20 years), and 40% new. The other plantations are 7 years old (I3) and 27-28 years old (I4).

In Dominican Republic, the main unit measure for land surface is the *tarea*, corresponding to 0.06288 hectares (ha). I1 reports that plantation total extension is 670 *tareas* (corresponding to 42.13 ha), but a part of the plantation is in renovation, so only 450 *tareas* (28.3 ha) are in production. I2 has a plantation of 228 hectares (corresponding to 3 626 *tareas*), while I3's plantation is of 100 *tareas* (6.29 ha). I4 declares they had 500 *tareas* and 30 *tareas* in extension (33.33 ha total).

Regarding productivity in 2016, I1 reports it was 70 200 boxes (3 boxes per *tarea* per week). I2's productivity was 395 000 boxes (but would normally have been 450 000). I3 reports a productivity of 180 boxes per week (9 300 boxes), but before the flood[1] it was 250 boxes per week (13 000 boxes per year). I4 has a productivity of 1 700 boxes per week (pre-flood average) (88 400 boxes per year).

Regarding the number of workers in the plantation: in the I1's plantation they have 35 permanent workers, and, in the day of cutting (one per week) they add from 15 to 20 more temporary workers. I2 reports as at the moment there are 122 people (all permanents) because there is less work (due to flooding). Normally there would be 230 people. In I3's plantation there are 8 workers in field and 6 temporary ones in packaging plant (they pack 1 time per week). I4 has an average of 70 Haitian workers: 35 permanents and 28/30 for harvesting/packing (it is harvested 2 days per week).

All the persons interviewed report they are part of a producers' association. I2 reports also they do not export trough this association, but they are directly in contact with the exporters.

Plantation particulars

All the four plantations examined are farmed on private land. The owners of the I1's plot of land are father and son (the person interviewed). I2 specify that the land was purchased with title by the company. Small plantations (I3 and I4) has an owner each one.

The four persons interviewed report they produce only bananas. All the extension is dedicated to banana cultivation.

They all produce banana for export, but production rejection is sold on local market. I1 declares a rejection of 5-10% of the total production, I2 of 5%, I3 of 7-8% and I4 of 12-15%.

All of them confirm the use of service providers only for treatments against Sigatoka.

Regarding the work management in the plantation:

- I1 reports they do not have a "phyto team" because they do not apply herbicides or nematicides in the field.
- I2 reports as his farm works differently than the others. The packing people do packing, the field workers makes only field. And in the field, they have workers assigned by area. They call them "*finqueros*". *Finqueros* do all the farm work. Those who do cluster spraying only do fumigation of the cluster. He declares they try to get people specialized in a task to improve performance. The president declares also that, before the flood, there were 30 people in packing, 40 in harvest, and 130 in the field. Of these 130 in the field, 50% are in charge of phytosanitary treatments.
- I3 and I4 do not have a team of people only applying pesticides (the so called "phyto team").

Regarding the use of Personal Protective Equipment (PPE):

- I1 declares they used the following PPE: gloves, face mask and rubber boots. At the same time, he declares also:

  "You have to fight with the workers to have it put. Sometimes the mask is put on the head because it is very uncomfortable."

- I2 reports as their "phyto teams" use:

  "Gloves, boots and mask when they want to put them. We bought all the equipment, but, in the end, they are not used."

  He reports, in this field, difficulties linked to temperature and humidity in wearing the PPE.

- I3 declared they use:

  "The legal required: boots, mask, gloves."

- I4 declared they use:

  "Gloves, long sleeve shirt, mask, boots."

At this state, of the interviews we analyse the place of storage of plant protection products and PPE.

- I1 declares that they do not have a specific place to store plant protection products because he does not use them. He has a specific place where he puts PPE, and as soon as workers have finished using them, they leave it there, each one has its own material and is responsible for its own material. PPEs are washed and reused the next day. He does not answer regarding the existence of a place where workers can keep their clean clothes.
- I2 reports they store plant protection products and PPEs in the warehouse. They do not have a place where workers can store their clean clothes. PPEs used are left on the field, they leave them where they arrived to treat, and they put it back the next day.
- I3 does not answer the questions regarding these subjects.
- I4 narrates they store plant protection products in the warehouse, but, also, that they buy the quantities they will use. In this manner they do not have to store much product. He does not refer if they have a specific place to store PPEs, and about what do they do with the already used Personal Protective Equipment. They leave the protective material on the farm. Workers are responsible for their own material.

Then, we move to "PPE policies". I1 tells us they give lectures, training programs. Regarding the frequency, he reportes that every year GlobalGap certification forces certified planters to do a training. They do not provide cash payments to try to incentive PPE wearing. He reports that if the workers do not put it on, they are not allowed to work. Regarding training on technical gestures for the protection of plants, he tells:

"Yes, we do it ourselves, but also the association. But we are the main ones. More or less the same worker does the same job. Every day we tell them something new.

Workers are formed to defoliation, deflowering, de-suckering and irrigation also."

I2 reports:

"Yes, we work (on this subject) *with them* (the farmworkers) *before the certification people come, so they understand that certifiers are coming, and they try at least to wear the equipment while the auditor is here.*

We have a person in charge of certifications that train them on the procedures of the standard."

[1] For more information, see: http://www.bbc.com/news/world-latin-america-37988308 .

They do not provide cash payments to incentive PPE wearing, but the permanent staff of each job is corrected continuously on technical gestures for the protection of plants. In the field, there are 5 coordinators that ensure that the work is correctly done.

I3 does not answer the questions regarding these subjects.

I4 reports they organise several times per year trainings on pests' harmfulness and/or pests linked diseases because certification requires it. They provide training on hygiene, material and risks, emergencies (assistance). The training is done by the association of producers, GlobalGap, themselves, ISA (local institute). They do not provide cash payments, but

"If they (workers) *do not use the material they are suspended."*

He does not answer about trainings on technical gestures for the protection of plants.

Regarding the role of producers' associations in providing services for plant health activities, I1 reports they do trainings:

"When the school year begins, the association gives a "help" to the workers. In December, for Christmas it also gives them a "help".

The association is thinking about joint purchases, but it is still not done.

I2 tells us the association they are part of does not provide services.

"Some producers' associations do, but X does not. With X you can buy joint supplies, but we do not go through them, we buy on our own."

I3 reportes that:

"Y gives them technical service (the technician comes once a week). A quality inspector from Z (the exporter) *comes to see quality management as well. The association gives them training. Certification (Faritrade, GlobalGap) requires them to train regularly, several times a year."*

I4 tells the producers' association provide training and technical service (quality inspection, product advice, etc.).

Tasks evaluation

In this interview section, we examine what of the plantation steps listed at § 4.1.3 are implemented in a single crop.

Destruction of the old plantation

I1 implements this step with machete.

"We lay and chop everything with a machete and with tractor we prepared the ground. We let it decompose."

Regarding timing:

"It depends on the size, e.g. the 20 tareas we are renovating takes 1 month with decomposition and everything."

I2 declares they fall by hand and pass a bulldozer to incorporate organic matter. They leave it for 3 months of decomposition and tillage.

I3 and I4 declare they have not renewed plantation.

Fallowing

All the four interviewed persons report they do not implement the fallowing step.

Nursery

I1 and I2 are building a nursery in this time. I3 and I4 do not implement this step.

Nursery (shadehouse)

I1 states that the nursery they are going to do is going to be to harden, but not yet. Currently they buy ready-to-plant sprouts.

I2 affirms that currently they do not have a shadehouse, but in a couple of weeks they can have one. I2 affirms also that it is not necessary to do fungicide treatments in the nursery, if it is well constructed.

I3 declares that they have not planted anything nor renewed.

I4 reports that for new surfaces, they make their own nursery (takes out "*colmitos*" and makes its own nursery with the sprouts).

Fertilization

I1 declares they have two types of fertilization:

1. Do soil analysis and correct depending on the result. During the year on average 4 ounces per plant, each month. That is, 48 ounces per plant per year.
2. With organic matter (compost) with farm waste and livestock manure. It is manual fertilization. With one measurement (2-inch PVC plugs = 4 ounces). Any worker can do it, everyone on the farm knows how to do it.

I2 does not use blends, they use raw materials. Potassium sulfate, ammonium sulfate. 12 times a year. They use manual fertilization.

I3, depending on the soil analysis, makes organic mineral and mineral fertilization. They use 3 ounces of mineral blend, every 45 days.

I4 uses mixture and organic: organic potassium sulfate and Bioles (liquid compost).

Weed control

I1 declares they implement weed control with machete, every week. Where it grows the most, they do it.

In the I2's plantation they do mechanical and chemical weed control: ammonium glucosinate (FINAL Bayer), every 6 weeks with manual spraying (back pump). To avoid leakage, they dilute the product in storage at 50% concentration. It is, then, diluted to a plastic tank in the field and it is put into the back pump and applied.

In I3's farm weed control is mechanical only. The producers' association (Y) has decided not to do chemical weeding.

I4 confirmes that weed control is manual only, because the producers' association (Y) prohibits the use of herbicides.

Control of Sigatoka

Regarding treatments to control Sigatoka, I1 declares they have 12 Sigatoka applications in 2016 (not normal). Normally it would have been 8. The service provider company is FUMCA. Regarding the exposure of workers during the treatments, he states:

"There are no workers on the plantations on the days we fumigate, we do it on Sundays to avoid that. The law says that the workers have to leave for 2 hours, but we do it on Sundays, so there is no one."

I2 reports they treat usually 10 to 12 times a year. Last year they finished in 10. The service provider company is FUMCA.

"But we prepare everything, the choice and the mixture of products and we give it to the plane that takes it and applies it. The warehouse boy arrives at 5 am, prepares the mixture of our products, and leaves it for the plane. To make sure that the products are ours, that everything is used well. And FUMCA gives us a certificate from a company that recycles the containers."

I3 confirms they use service providers for treatments against Sigatoka. The technician of the producers' association (Y) indicates which is product to use. They resort to aerial treatment from an external company, but from time to time manual treatment with back pump. They treat from 10 to 11 times a year, on average 5 with plane, the rest manually. The service provider company is not FUMCA, but he does not confirm it is CODEACA[2].

I4 declares that, for Sigatoka treatments, external company provides the service with airplane (10 times per year). But if there is an emergency, 1 or 2 people with *motobomba* make other applications. Product and quantities are indicated by the technician of the producers' association (Y).

Control of other pests and diseases

Regarding this issue, I1 confirms they do not treat for other diseases.

I2, I3 and I4 declare they treat against thrips within bunch bags. This activity will be deepened in the next paragraph.

I4 reports also that they treat against weevil, trapping with pheromones, and nematodes, treating once a year with VERANGO by BAYER.

Bunch care

I1 declares to use conventional bag impregnated with DURSBAN. In this case workers wear long sleeves and gloves. The bags are placed by hand with a ladder. They put Prematol to the cover to combat the thrips. The bag is lifted and leaved above for the deflower, and then it is put lower again.

I2 declares that the bunch bag is placed, opened and fumigated inside with the back-pressure pump.

For thrips, the cluster is sprayed 1 time per week with Texal (Espinosat).

The sheath is impregnated with Dursban but loses effectiveness and to reinforce they use the thrips product. To deflower, the bag is opened again by hand.

I3 confirms they use bags with DURSBAN (chlorpyrifos). Fumigation for thrips with back pump is made once a week. The product is Espinoace, red oxide. The same worker deals with the fumigation (each worker has his job).

I4 declares they use non-impregnated bags because the plantation is in organic transition, but for thrips, they made 3 fumigations per week (ESPINOACE, EXALT, BIONIM).

Post-harvest treatments (in the packaging plant)

I1 states that:

> *"On Tuesday, we are going to the packing house. We remove the bag, we cut the different hands (desmane), we throw the hands to the tub with DISPERLATEX (like a soap) in a dropper, selected by size. Bananas are weighed, fumigated with a pump by hand, sealed, some in a bag, packed, palletized and into the container. Those who work in the packing house are specific, but some permanents come to help."*

I2 declares that latex is washed in the tub with a specific soap. Bananas are treated with GIBBERELLINS to stop the ripening process. Spray fungicide is applied to the crown.

I3 reported they use ALUMER in the tub, and BIOCITRON (antifungal) and IMAZALIL on the crown by spraying.

I4 declared to use DISPERLATEX in the tub, and to spray the crown with BIOCITRON BIO.

Cleaning instruments

In this interview section, we ask about the existence of an instrument cleaning phase, and, if yes, in which way it is implemented.

I1 states that everyday tools are cleaned and stored as soon as the work is finished, every day by each worker. The packing's instruments are washed the next day because they finish packing too late. It exists a waste water management processes only in the packaging plant, where latex washing goes through a drain.

I2 reports that every worker cleans his tool and stays there until the next day. The cleaning phase is implemented in the plantation, although it should be done in a coal pit. It doesn't exist a waste water management processes.

I3 confirms that the instruments are cleaned every day, by each worker. Regarding the existence of a waste water management processes, he declares:

> *"The water in the tub goes to an underground well. The rest of the waters go to a canal (which then flows into a river or into the normal drainage)."*

I4 states that pumps and knives and other tools are cleaned instantly, packer stuff, if it's too late when they finish they clean them the next day. The cleaning phase is implemented in a cleaning area. He stated also that the wastewater goes to a draining and, then, in a drain.

Information collected through these interviews were added to knowledge (§ 4.1.3) and decision trees (§ 4.1.4) we devised, and, consequently, in the calculation structure of the indicator.

Questions for plantation workers

In no-one of the plantations visited we had the opportunity to interview plantation workers.

[2] From the context analysis emerged that there are two companies of fumigation: FUMCA and CODEACA.

Annex 5 - Significant images collected during the case study observation

Figure 5.1 – Preparation task carried out before herbicide application (Dominican Republic)

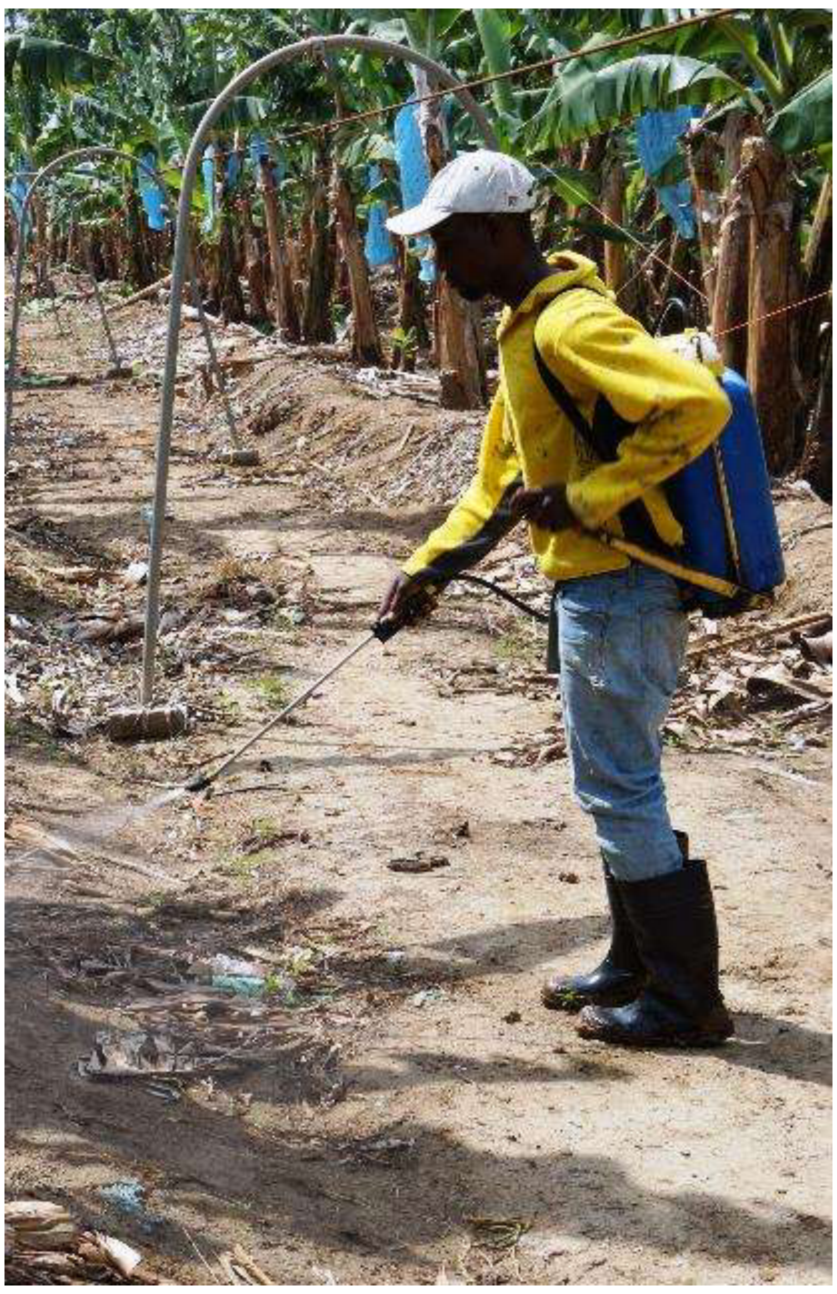


Figure 5.2 – Herbicide application task carried out in banana plantation (Dominican Republic)

Figure 5.3 – An operator applying a fungicide on banana crowns without mask and glasses (Dominican Republic)

Figure 5.4 – An operator applying a fungicide on banana crowns using a t-shirt as a mask (Dominican Republic)

Annex 6 - Publications in relation to this dissertation

Di Cesare S., Macombe C., Petti, L., Loeillet, D. (2016). Necessity of including the evaluation of pesticides impacts on farmworkers health in social LCA. 5th International Conference in Social Life Cycle Assessment, Harvard University, Cambridge (US), 13th – 15th June. Book of abstracts – SLCA 2016, pp. 6-7

Di Cesare S., Feschet P., Macombe C., Petti L., Loeillet D. (2016) Conceptualizing a new method to evaluate banana farmworkers pesticides exposure. X International Symposium on Banana/ISHS-ProMusa symposium, Montpellier (France), 10th – 14th October. Book of abstracts, p. 66

Di Cesare S., Macombe C., Grimbuhler S., Feschet P., Petti L., Mathé S., Loeillet D. (2017) Evaluating exposure to pesticides in banana production systems: an expert elicitation approach. 11th Conference of the Italian LCA Network. University of Siena (Italy), 22nd – 23rd June. Atti del XI Convegno della Rete Italiana LCA Resource Efficiency e Sustainable Development Goals: il ruolo del Life Cycle Thinking. ISBN: 978-88-8286-352-4, pp. 150-158

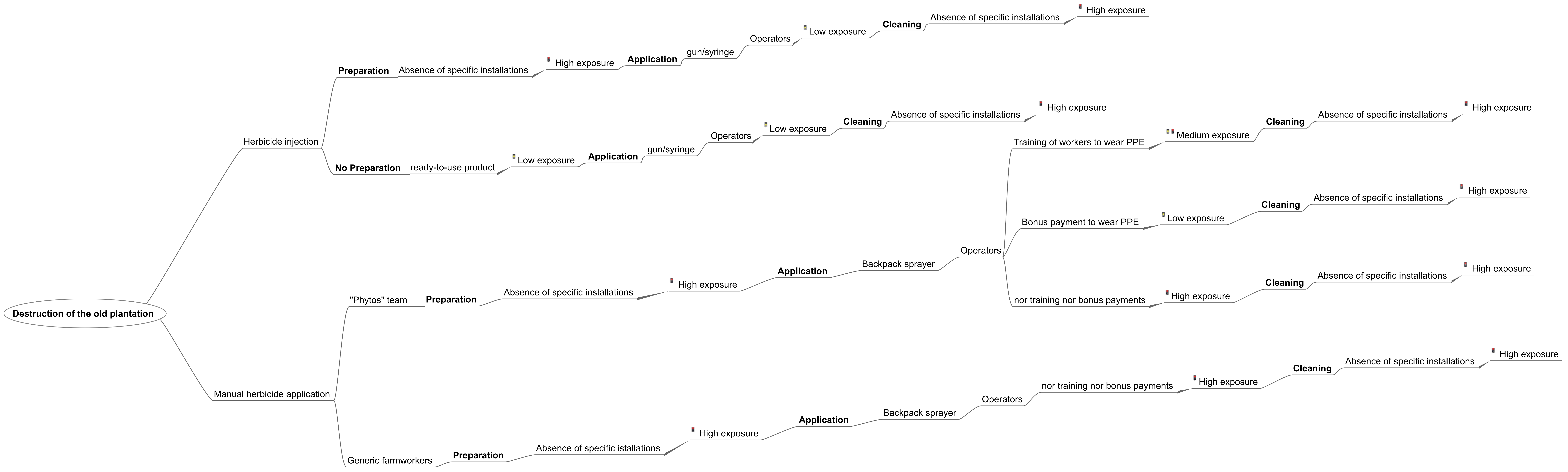
Di Cesare S., Macombe C., Petti L., Loeillet D. (2017) Rooting LCA methods in experts' knowledge: Human cost of pesticides caused by agricultural practices. SETAC Europe 27th Annual Meeting, Brussels (Belgium), 7th – 11th May 2017. Book of abstracts.

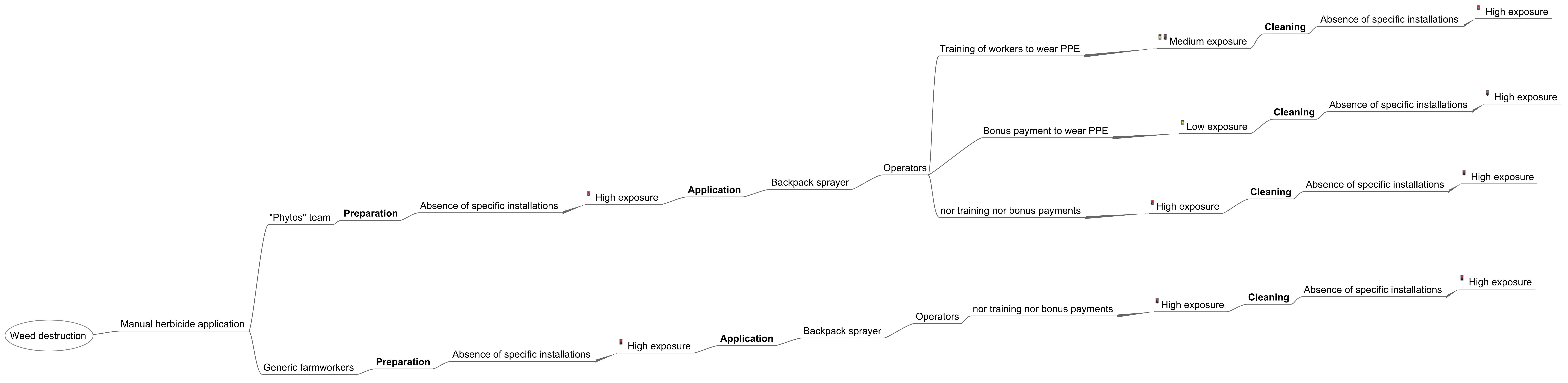
Di Cesare S., Mathé, S. (2017) Mobilizing stakeholders to anticipate impacts., in: Macombe C. (ed.) 2017, Social evaluation of the life cycle, application to the agriculture and agri-food sectors. FruitropThema, Montpellier, pp. 186-195. ISBN: 978-2-9562141-0-6

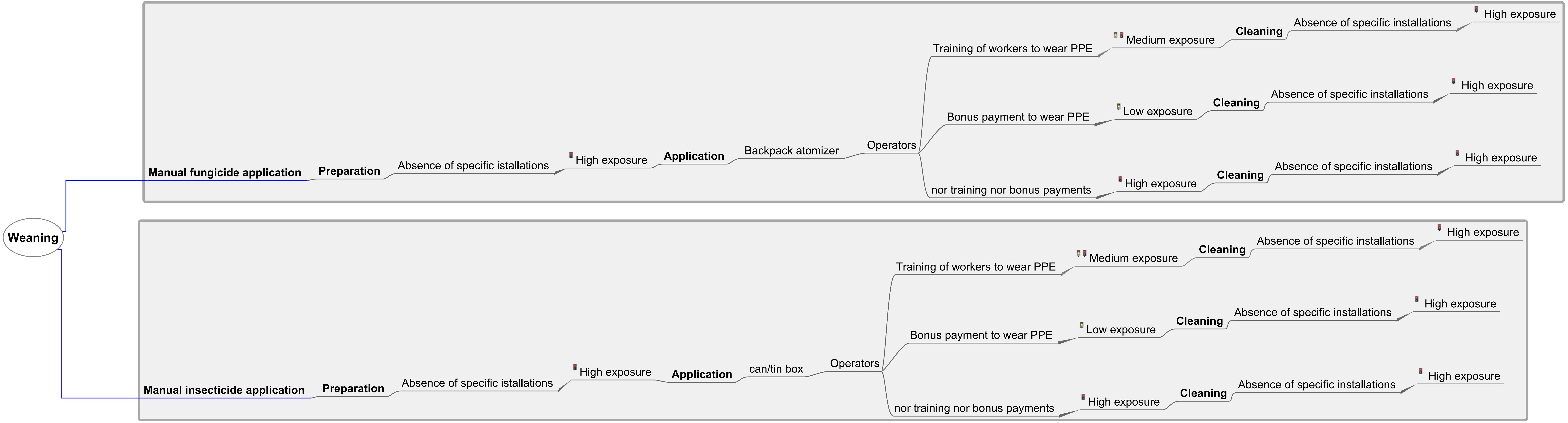
Di Cesare S., Macombe C., Loeillet D. (2017) The Wesseling pathway - The assessment of farmworkers exposure to pesticides., in: Macombe C. (ed.) 2017, Social evaluation of the life cycle, application to the agriculture and agri-food sectors. FruitropThema, Montpellier, pp. 164-173. ISBN: 978-2-9562141-0-6

Di Cesare S., Macombe C., Petti L., Loeillet D. Are the impacts of Plant Protection Products on farmworkers health, effectively assessed? A critical review for tropical regions. Journal of Cleaner Production. Submitted.

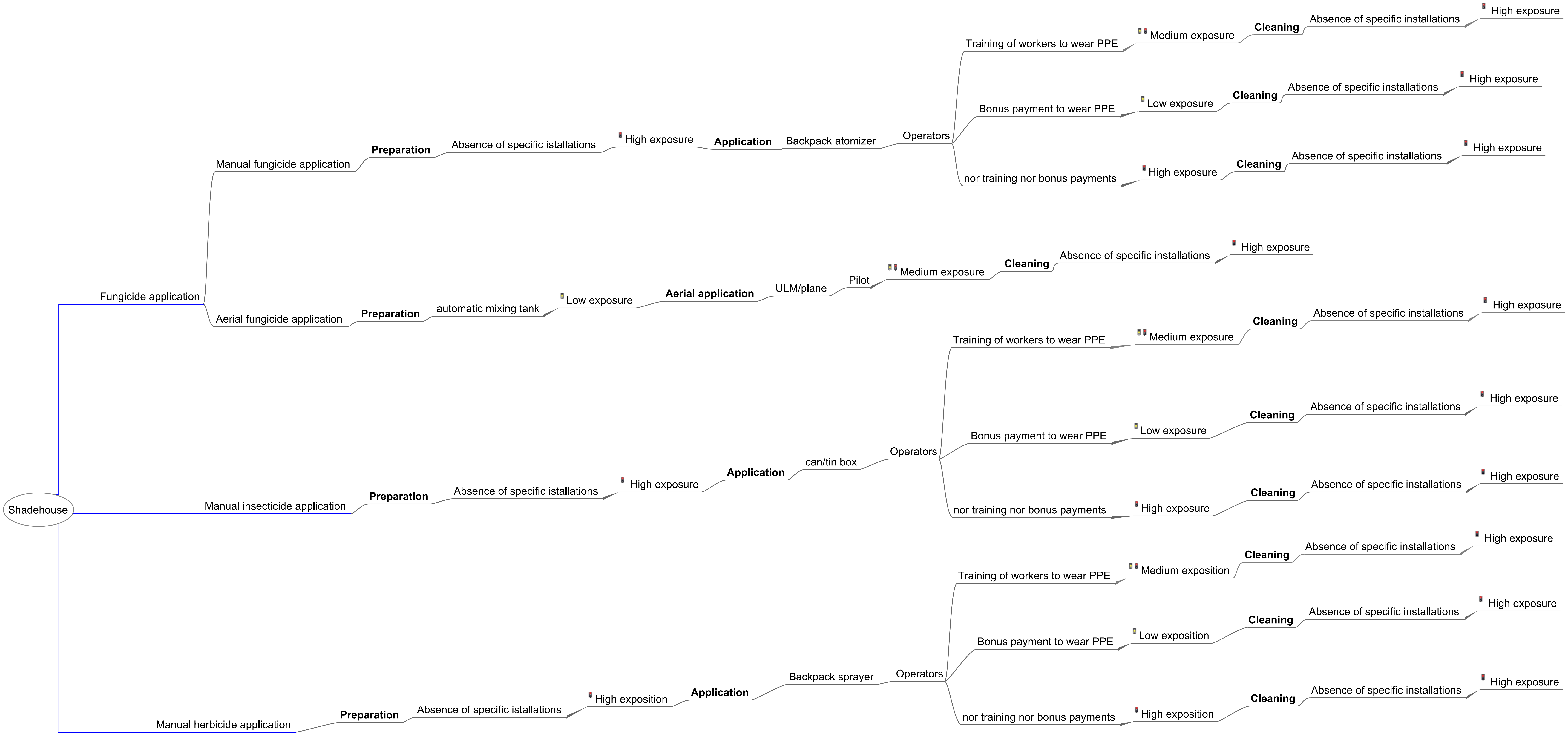
Annex 7 – Knowledge trees devised through the Delphi experts consensus method

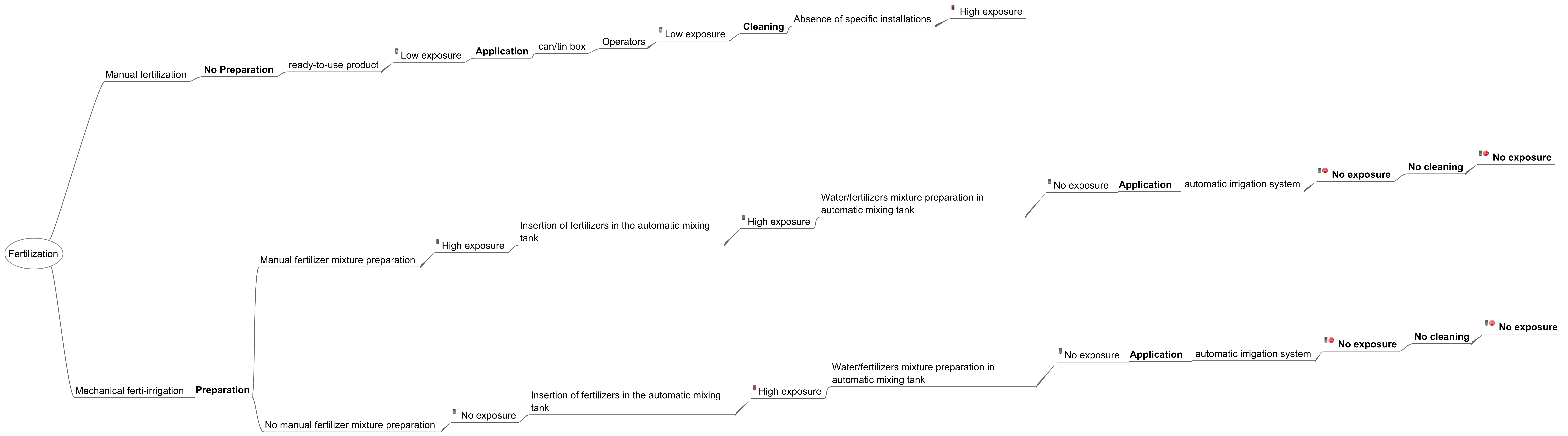

Destruction of the old plantation
Herbicide injection
Preparation
Absence of specific installations
High exposure
Application
gun/syringe
Operators
Low exposure
Cleaning
Absence of specific installations
High exposure
No Preparation
ready-to-use product
Low exposure
Application
gun/syringe
Operators
Low exposure
Cleaning
Absence of specific installations
High exposure
Manual herbicide application
"Phytos" team
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific istallations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure

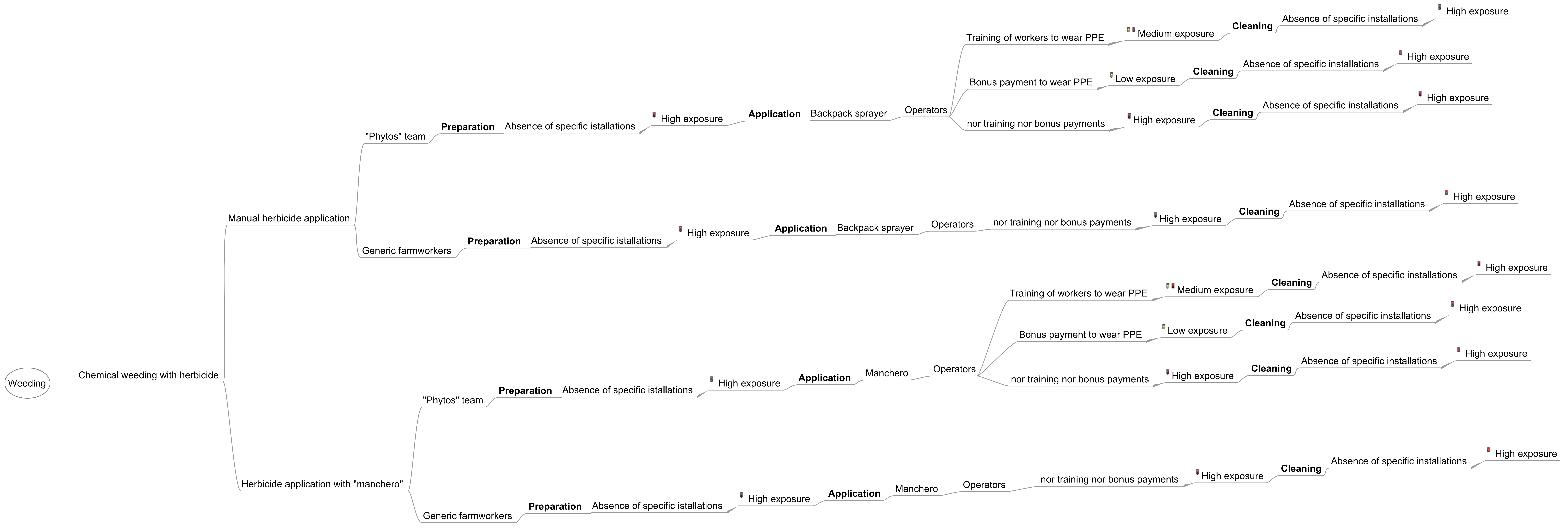

Weed destruction
Manual herbicide application
"Phytos" team
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure



Weaning
Manual fungicide application
Preparation
Absence of specific istallations
High exposure
Application
Backpack atomizer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Manual insecticide application
Preparation
Absence of specific istallations
High exposure
Application
can/tin box
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure

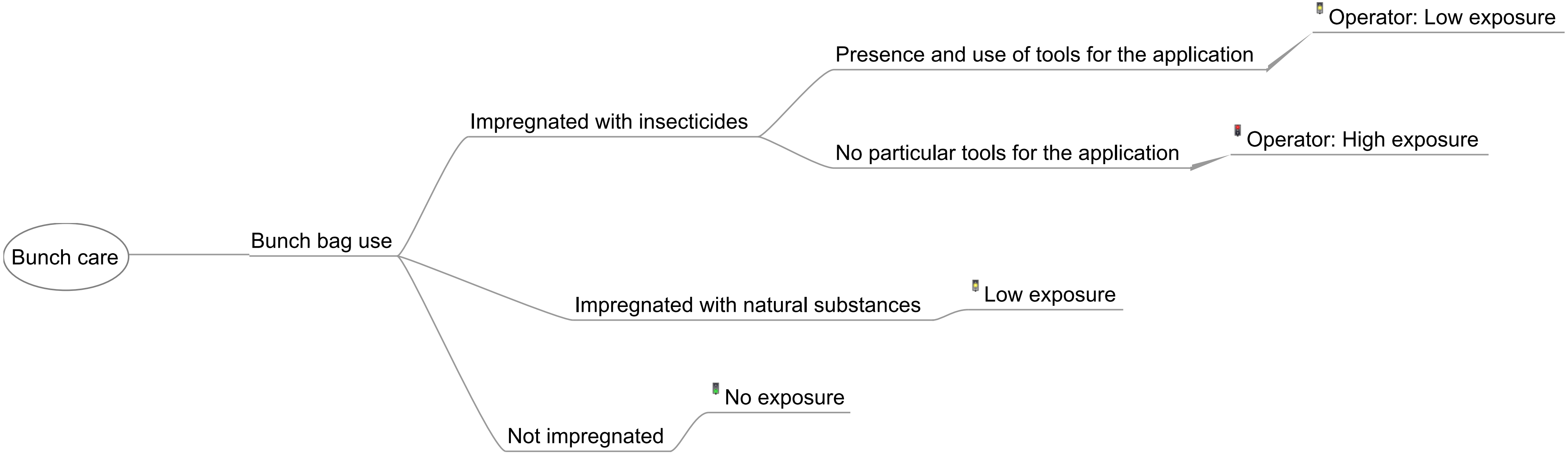

Shadehouse
Fungicide application
Manual fungicide application
Preparation
Absence of specific istallations
High exposure
Application
Backpack atomizer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Aerial fungicide application
Preparation
automatic mixing tank
Low exposure
Aerial application
ULM/plane
Pilot
Medium exposure
Cleaning
Absence of specific installations
High exposure
Manual insecticide application
Preparation
Absence of specific istallations
High exposure
Application
can/tin box
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Manual herbicide application
Preparation
Absence of specific istallations
High exposition
Application
Backpack sprayer
Operators
Training of workers to wear PPE
Medium exposition
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposition
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposition
Cleaning
Absence of specific installations
High exposure

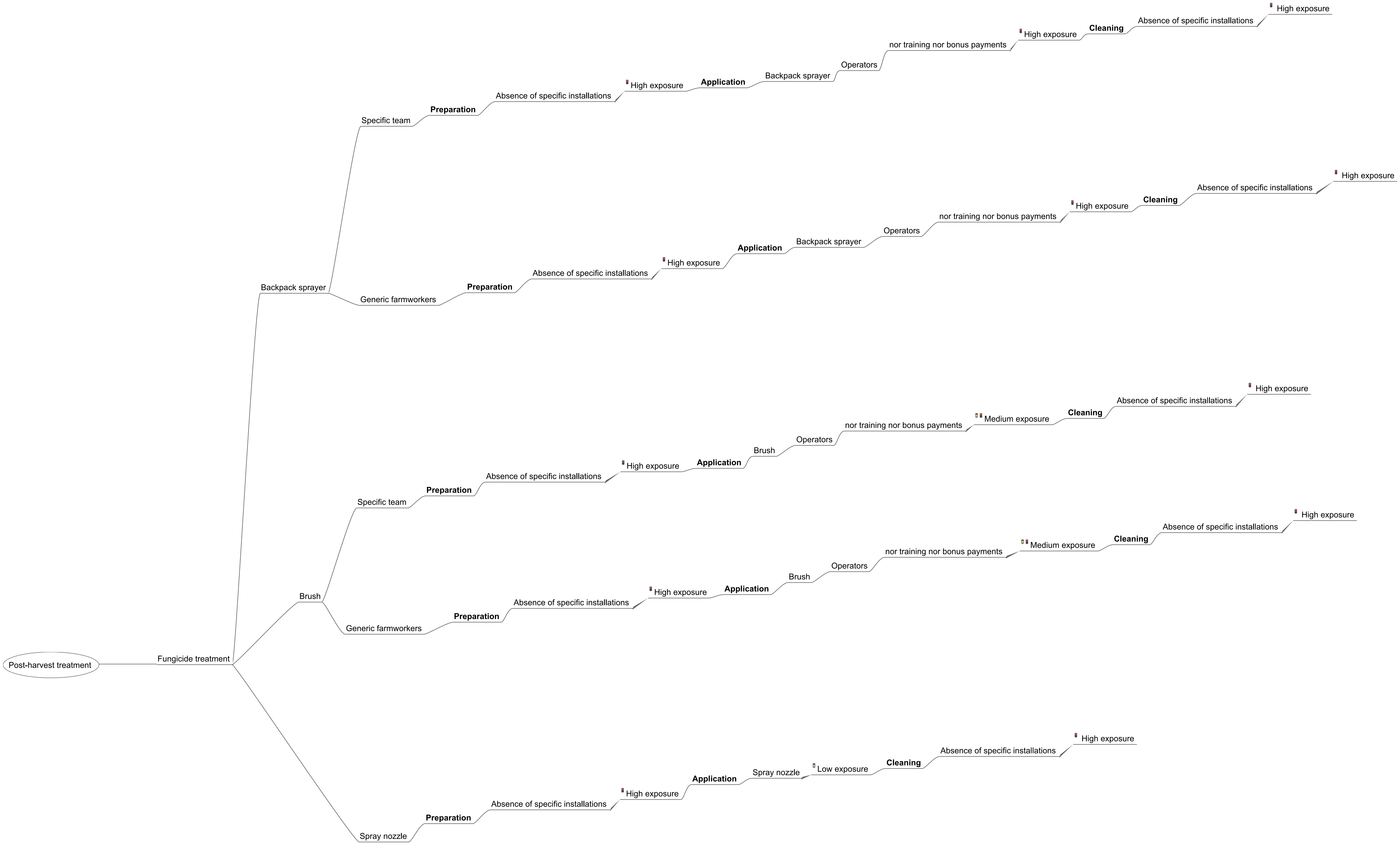

Fertilization
Manual fertilization
No Preparation
ready-to-use product
Low exposure
Application
can/tin box
Operators
Low exposure
Cleaning
Absence of specific installations
High exposure
Mechanical ferti-irrigation
Preparation
Manual fertilizer mixture preparation
High exposure
Insertion of fertilizers in the automatic mixing tank
High exposure
Water/fertilizers mixture preparation in automatic mixing tank
No exposure
Application
automatic irrigation system
No exposure
No cleaning
No exposure
No manual fertilizer mixture preparation
No exposure
Insertion of fertilizers in the automatic mixing tank
High exposure
Water/fertilizers mixture preparation in automatic mixing tank
No exposure
Application
automatic irrigation system
No exposure
No cleaning
No exposure



Weeding
Chemical weeding with herbicide
Manual herbicide application
"Phytos" team
Preparation
Absence of specific istallations
High exposure
Application
Backpack sprayer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific istallations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Herbicide application with "manchero"
"Phytos" team
Preparation
Absence of specific istallations
High exposure
Application
Manchero
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific istallations
High exposure
Application
Manchero
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure

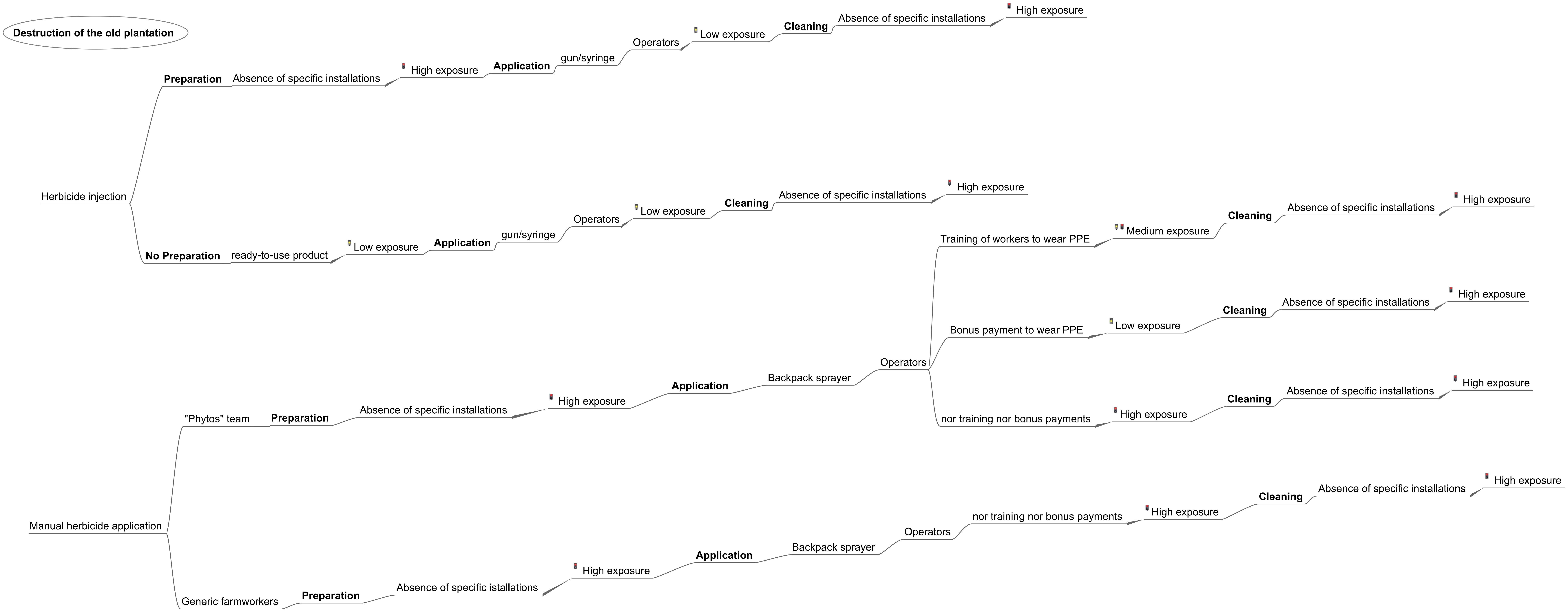
Plant protection
Fungicide treatment
Conventional chemical fungicides
Aerial fungicides application
Preparation
Cloed automatic mixing tank
Low exposure
Aerial application
Pilot
Medium exposure
Cleaning
Absence of specific installations
High exposure
Open Automatic mixing tank
Medium exposure
Aerial application
Pilot
Medium exposure
Cleaning
Absence of specific installations
High exposure
Mechanical/terrestrial fungicides application
Preparation
Closed automatic mixing tank
Low Exposure
Application
quad, cannon, Martinelli
Driver
Medium exposure
Cleaning
Absence of specific installations
High exposure
Open/Closed rural mixing tank
Medium exposure
Application
quad, cannon, Martinelli
Driver
Medium exposure
Cleaning
Absence of specific installations
High exposure
Absence of specific istallations
High exposure
Application
quad, cannon, Martinelli
Driver
Medium exposure
Cleaning
Absence of specific installations
High exposure
Manual fungicides application
"Phytos" team
Preparation
Absence of specific istallations
High exposure
Application
Backpack atomizer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific istallations
High exposure
Application
Backpack atomizer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Use of organic products as fongicides (ex. nettle juice, mineral oil, copper, sulfur, etc.)
No Preparation
ready-to-use product
Low exposure
Application
Backpack atomizer
Operators
High exposure
Cleaning
Absence of specific installations
High exposure
Weevil&Nematodes treatment
Use of uncontaminated planting material
No exposure
Pseudostem/stump trap
with insecticide (liquid or granular)
Preparation
Absence of specific installations
High exposure
Application
Gun
Operator
Low exposure
Cleaning
Absence of specific installations
High exposure
without insecticide
No exposure
No cleaning
No exposure
Use of uncontaminated planting material
No exposure
Fallowing
No exposure
No cleaning
No exposure


Bunch care
Bunch bag use
Impregnated with insecticides
Presence and use of tools for the application
Operator: Low exposure
No particular tools for the application
Operator: High exposure
Impregnated with natural substances
Low exposure
Not impregnated
No exposure

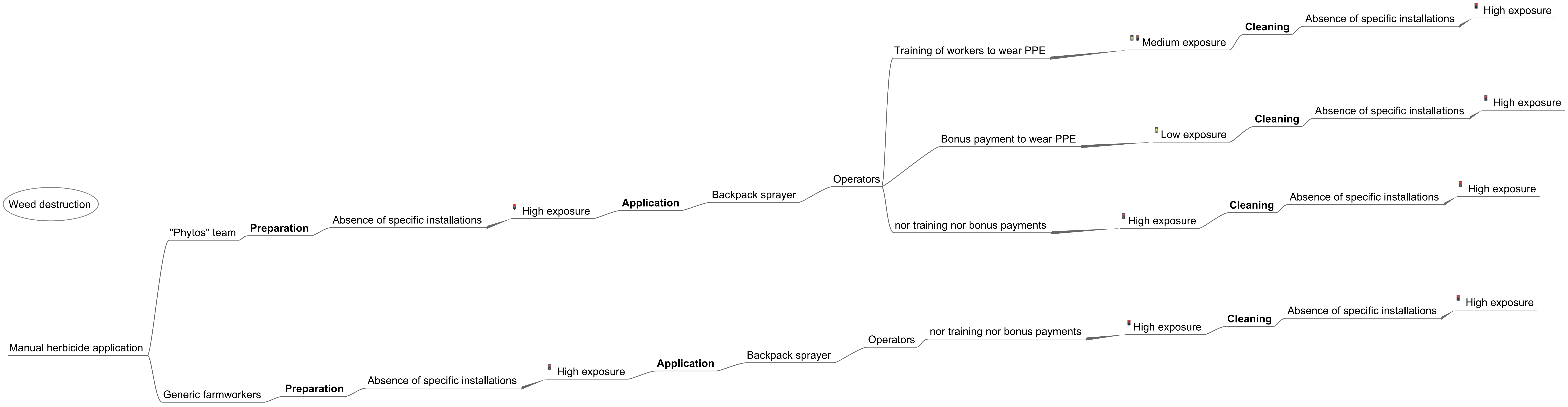


Post-harvest treatment
Fungicide treatment
Backpack sprayer
Specific team
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Brush
Specific team
Preparation
Absence of specific installations
High exposure
Application
Brush
Operators
nor training nor bonus payments
Medium exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific installations
High exposure
Application
Brush
Operators
nor training nor bonus payments
Medium exposure
Cleaning
Absence of specific installations
High exposure
Spray nozzle
Preparation
Absence of specific installations
High exposure
Application
Spray nozzle
Low exposure
Cleaning
Absence of specific installations
High exposure

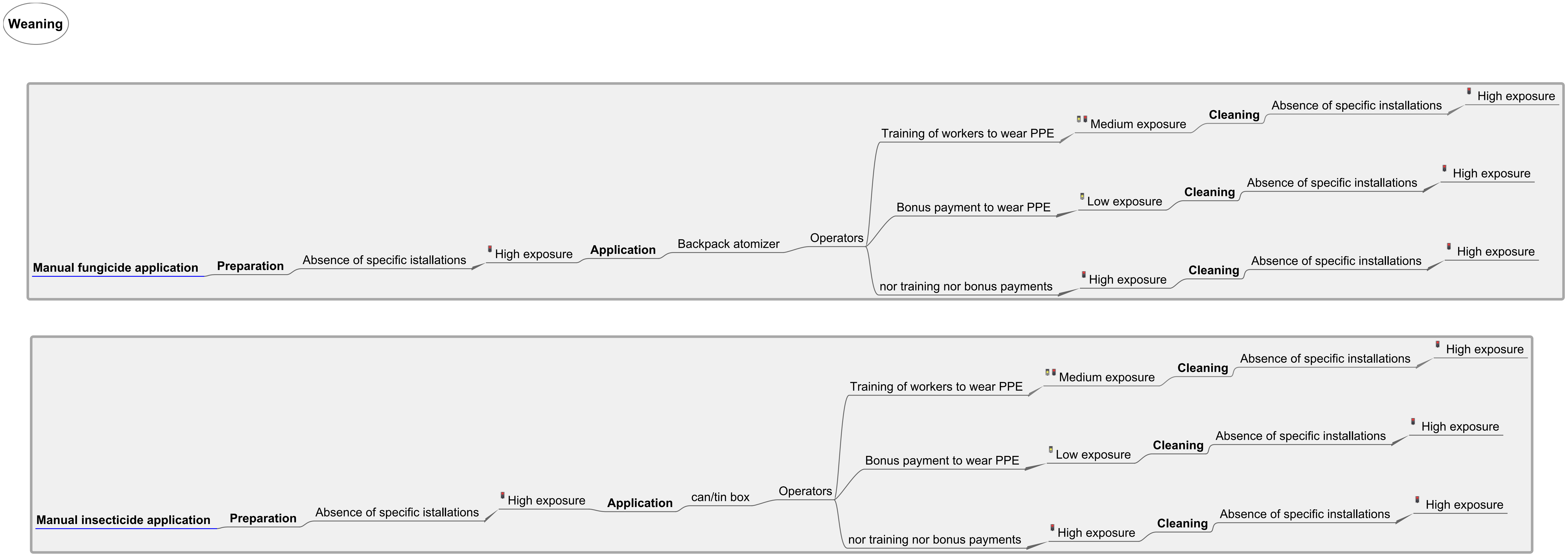
Annex 8 – Decision trees deriving from knowledge trees



Destruction of the old plantation
Herbicide injection
Preparation
Absence of specific installations
High exposure
Application
gun/syringe
Operators
Low exposure
Cleaning
Absence of specific installations
High exposure
No Preparation
ready-to-use product
Low exposure
Application
gun/syringe
Operators
Low exposure
Cleaning
Absence of specific installations
High exposure
Manual herbicide application
"Phytos" team
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific istallations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure

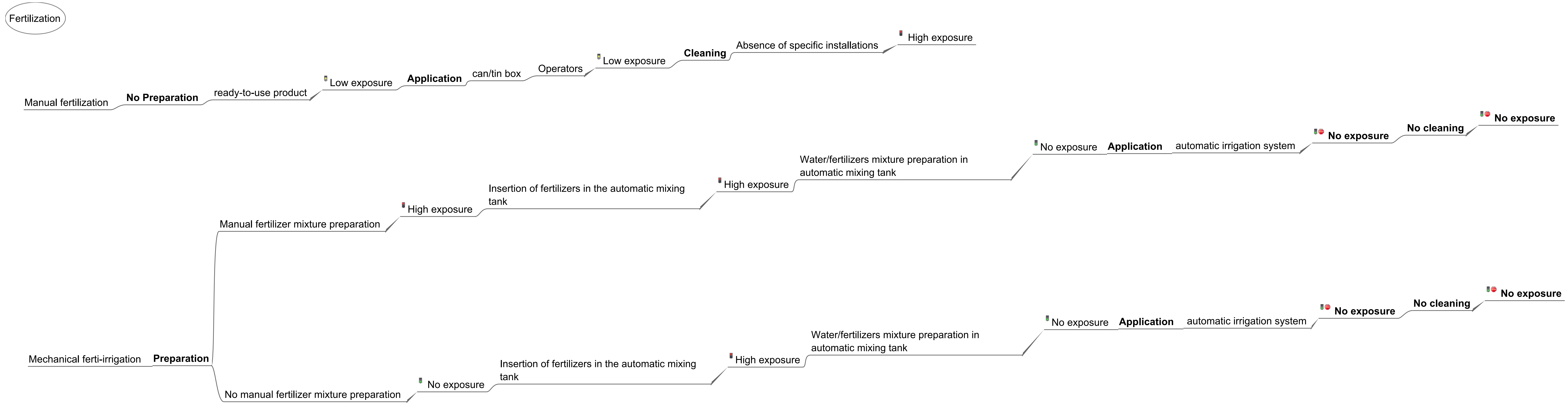


Weed destruction
Manual herbicide application
"Phytos" team
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure

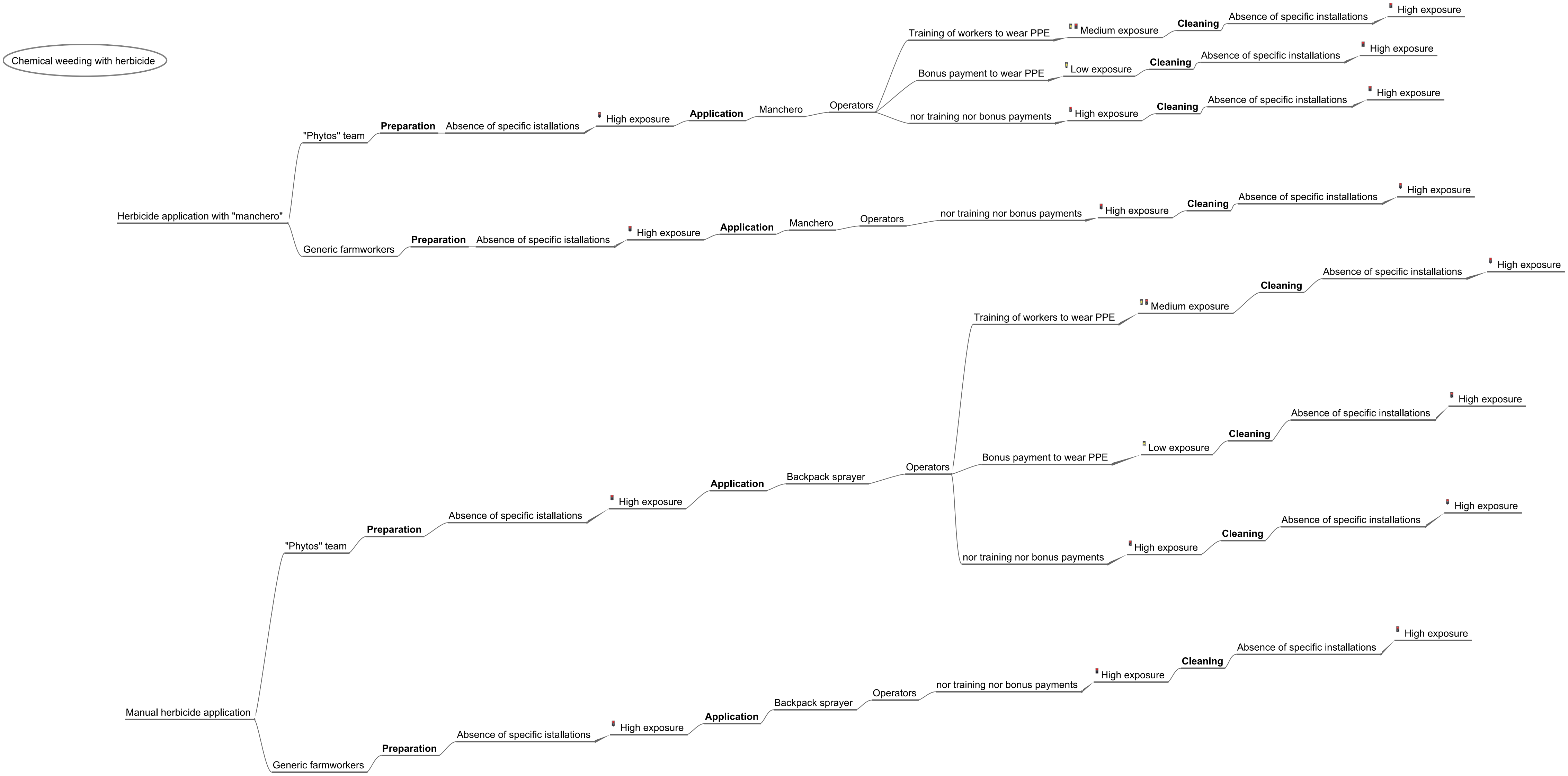


Weaning
Manual fungicide application
Preparation
Absence of specific istallations
High exposure
Application
Backpack atomizer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Manual insecticide application
Preparation
Absence of specific istallations
High exposure
Application
can/tin box
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure

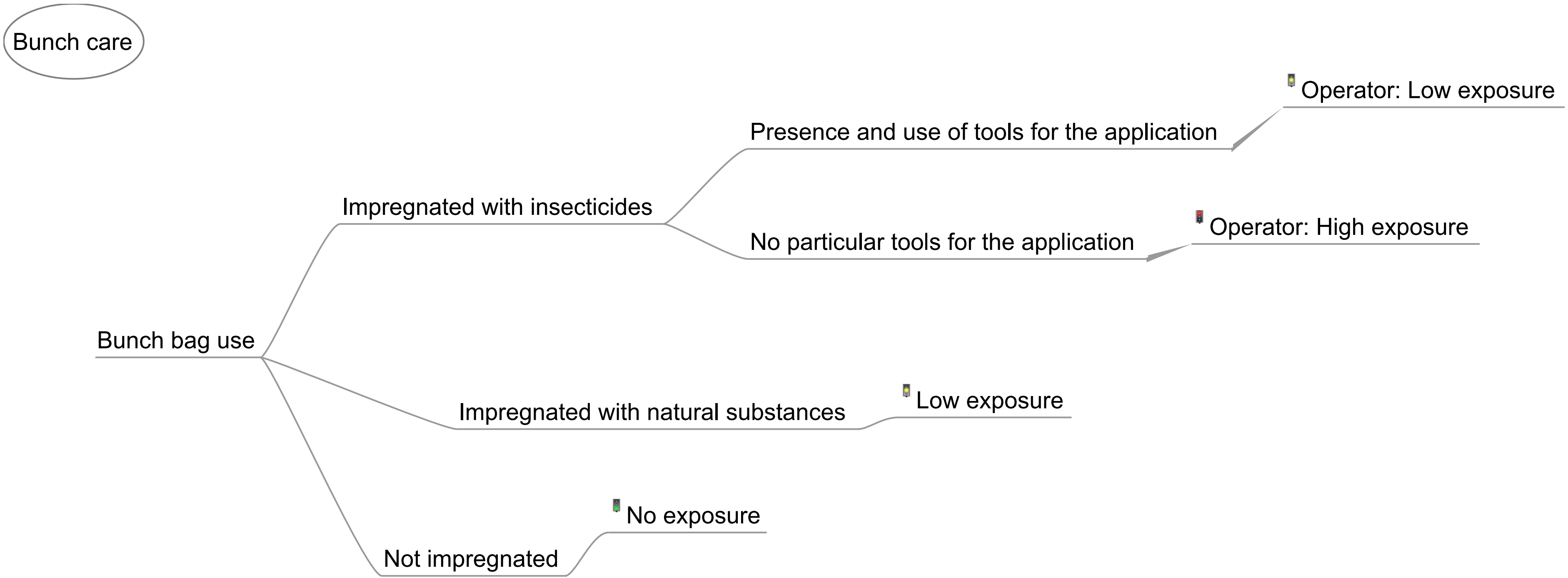
Shadehouse
Fungicide application
Manual fungicide application
Preparation
Absence of specific istallations
High exposure
Application
Backpack atomizer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Aerial fungicide application
Preparation
automatic mixing tank
Low exposure
Aerial application
ULM/plane
Pilot
Medium exposure
Cleaning
Absence of specific installations
High exposure
Manual insecticide application
Preparation
Absence of specific istallations
High exposure
Application
can/tin box
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Manual herbicide application
Preparation
Absence of specific istallations
High exposition
Application
Backpack sprayer
Operators
Training of workers to wear PPE
Medium exposition
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposition
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposition
Cleaning
Absence of specific installations
High exposure



Fertilization
Manual fertilization
No Preparation
ready-to-use product
Low exposure
Application
can/tin box
Operators
Low exposure
Cleaning
Absence of specific installations
High exposure
Mechanical ferti-irrigation
Preparation
Manual fertilizer mixture preparation
High exposure
Insertion of fertilizers in the automatic mixing tank
High exposure
Water/fertilizers mixture preparation in automatic mixing tank
No exposure
Application
automatic irrigation system
No exposure
No cleaning
No exposure
No manual fertilizer mixture preparation
No exposure
Insertion of fertilizers in the automatic mixing tank
High exposure
Water/fertilizers mixture preparation in automatic mixing tank
No exposure
Application
automatic irrigation system
No exposure
No cleaning
No exposure

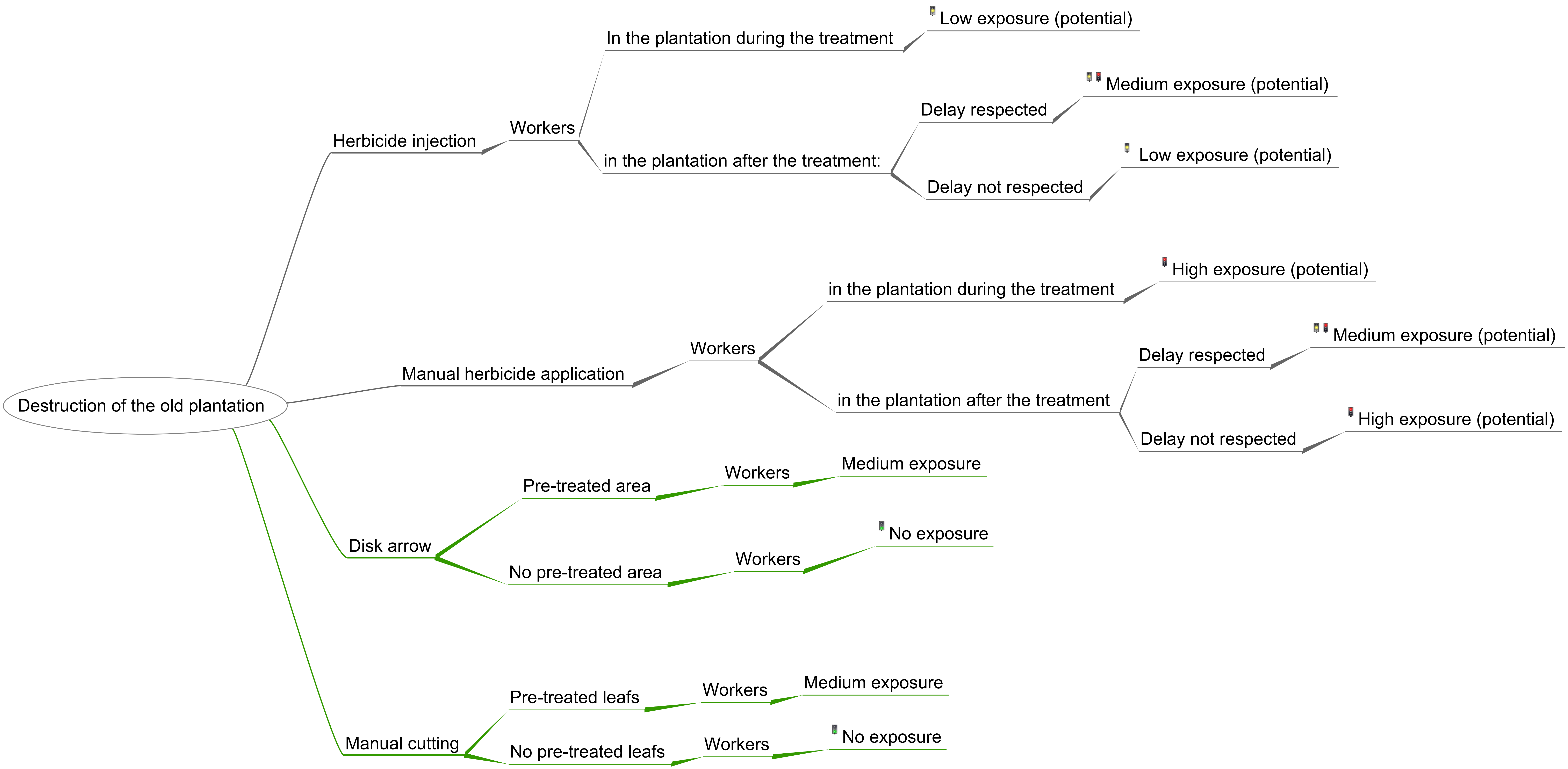

Chemical weeding with herbicide
Herbicide application with "manchero"
"Phytos" team
Preparation
Absence of specific istallations
High exposure
Application
Manchero
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific istallations
High exposure
Application
Manchero
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Manual herbicide application
"Phytos" team
Preparation
Absence of specific istallations
High exposure
Application
Backpack sprayer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific istallations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure

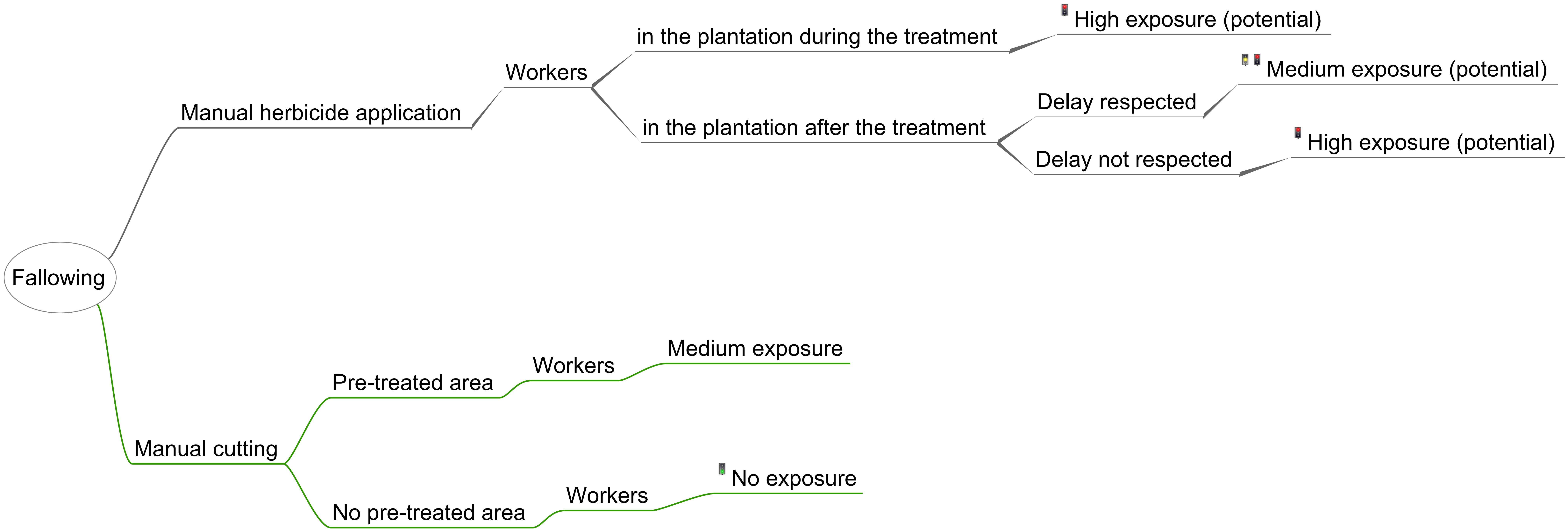

Plant protection
Fungicide treatment
Conventional chemical fungicides
Aerial fungicides application
Preparation
Cloed automatic mixing tank
Low exposure
Aerial application
Pilot
Medium exposure
Cleaning
Absence of specific installations
High exposure
Open Automatic mixing tank
Medium exposure
Aerial application
Pilot
Medium exposure
Cleaning
Absence of specific installations
High exposure
Mechanical/terrestrial fungicides application
Preparation
Closed automatic mixing tank
Low Exposure
Application
quad, cannon, Martinelli
Driver
Medium exposure
Cleaning
Absence of specific installations
High exposure
Open/Closed rural mixing tank
Medium exposure
Application
quad, cannon, Martinelli
Driver
Medium exposure
Cleaning
Absence of specific installations
High exposure
Absence of specific istallations
High exposure
Application
quad, cannon, Martinelli
Driver
Medium exposure
Cleaning
Absence of specific installations
High exposure
Manual fungicides application
"Phytos" team
Preparation
Absence of specific istallations
High exposure
Application
Backpack atomizer
Operators
Training of workers to wear PPE
Medium exposure
Cleaning
Absence of specific installations
High exposure
Bonus payment to wear PPE
Low exposure
Cleaning
Absence of specific installations
High exposure
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific istallations
High exposure
Application
Backpack atomizer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Use of organic products as fongicides (ex. nettle juice, mineral oil, copper, sulfur, etc.)
No Preparation
ready-to-use product
Low exposure
Application
Backpack atomizer
Operators
High exposure
Cleaning
Absence of specific installations
High exposure
Weevil&Nematodes treatment
Use of uncontaminated planting material
No exposure
Pseudostem/stump trap
with insecticide (liquid or granular)
Preparation
Absence of specific installations
High exposure
Application
Gun
Operator
Low exposure
Cleaning
Absence of specific installations
High exposure
without insecticide
No exposure
No cleaning
No exposure
Use of uncontaminated planting material
No exposure
Fallowing
No exposure
No cleaning
No exposure

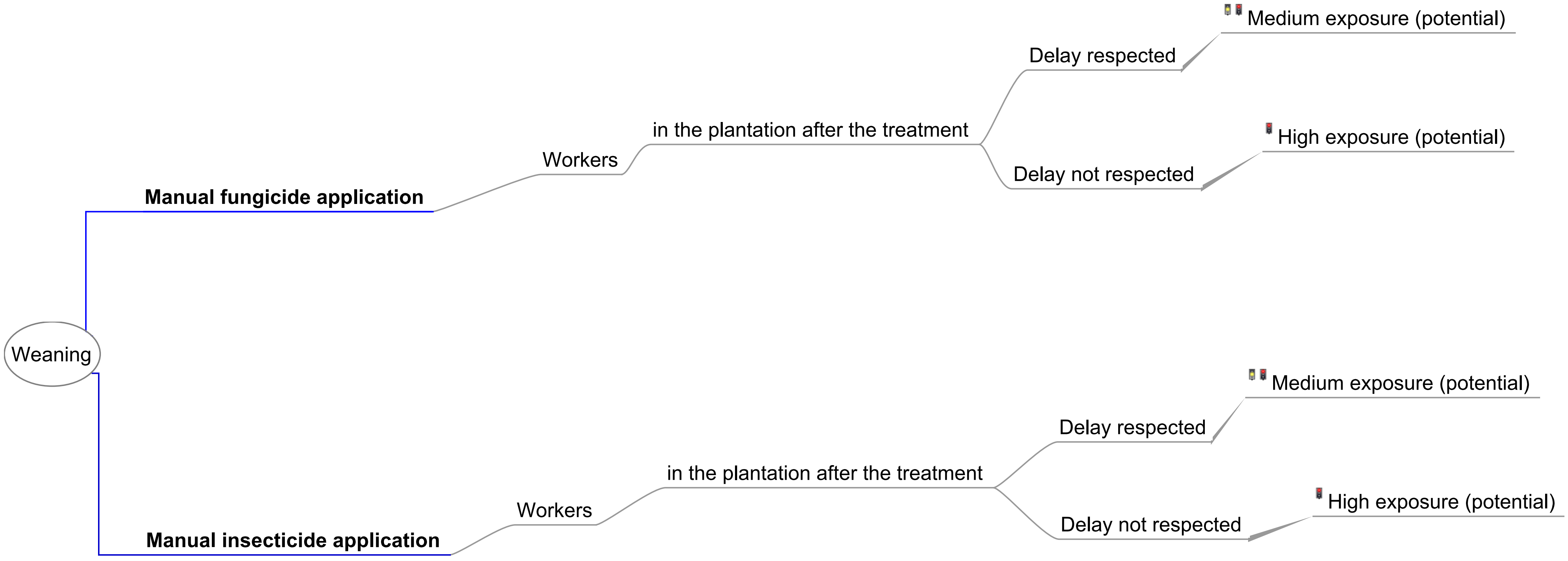

Bunch care
Bunch bag use
Impregnated with insecticides
Presence and use of tools for the application
Operator: Low exposure
No particular tools for the application
Operator: High exposure
Impregnated with natural substances
Low exposure
Not impregnated
No exposure

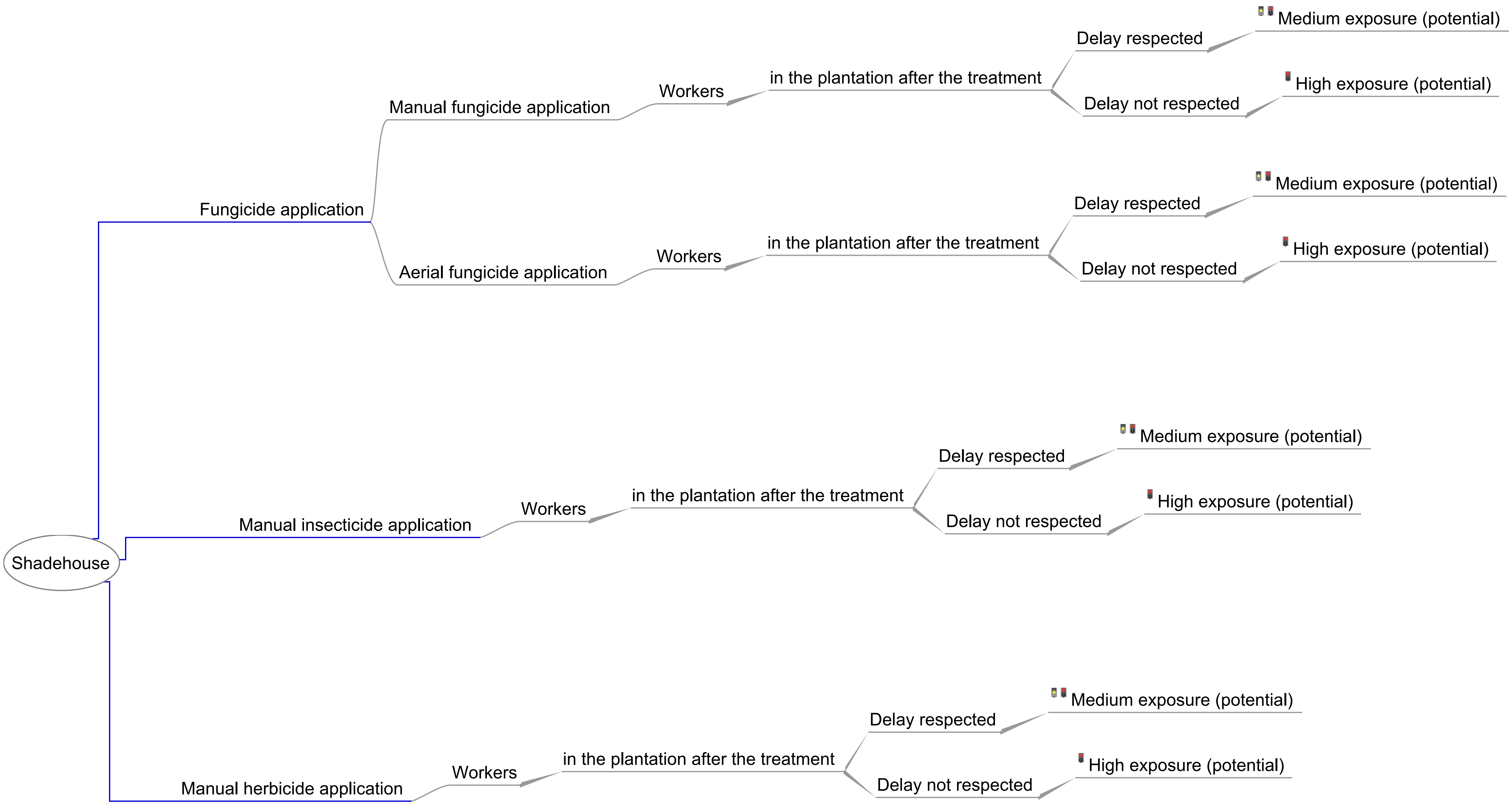
Post-harvest treatment
Fungicide treatment
Backpack sprayer
Specific team
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific installations
High exposure
Application
Backpack sprayer
Operators
nor training nor bonus payments
High exposure
Cleaning
Absence of specific installations
High exposure
Brush
Specific team
Preparation
Absence of specific installations
High exposure
Application
Brush
Operators
nor training nor bonus payments
Medium exposure
Cleaning
Absence of specific installations
High exposure
Generic farmworkers
Preparation
Absence of specific installations
High exposure
Application
Brush
Operators
nor training nor bonus payments
Medium exposure
Cleaning
Absence of specific installations
High exposure
Spray nozzle
Preparation
Absence of specific installations
High exposure
Application
Spray nozzle
Low exposure
Cleaning
Absence of specific installations
High exposure

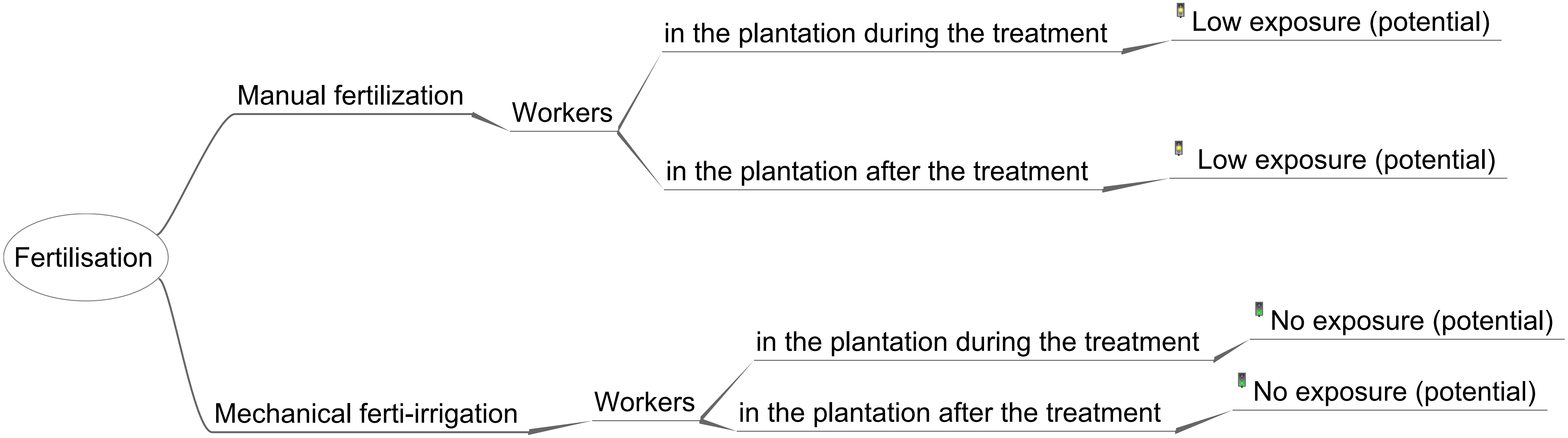
Annex 9 – Possible formalisation of knowledge trees for generic farmworkers


Destruction of the old plantation
Herbicide injection
Workers
In the plantation during the treatment
Low exposure (potential)
in the plantation after the treatment:
Delay respected
Medium exposure (potential)
Delay not respected
Low exposure (potential)
Manual herbicide application
Workers
in the plantation during the treatment
High exposure (potential)
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)
Disk arrow
Pre-treated area
Workers
Medium exposure
No pre-treated area
Workers
No exposure
Manual cutting
Pre-treated leafs
Workers
Medium exposure
No pre-treated leafs
Workers
No exposure

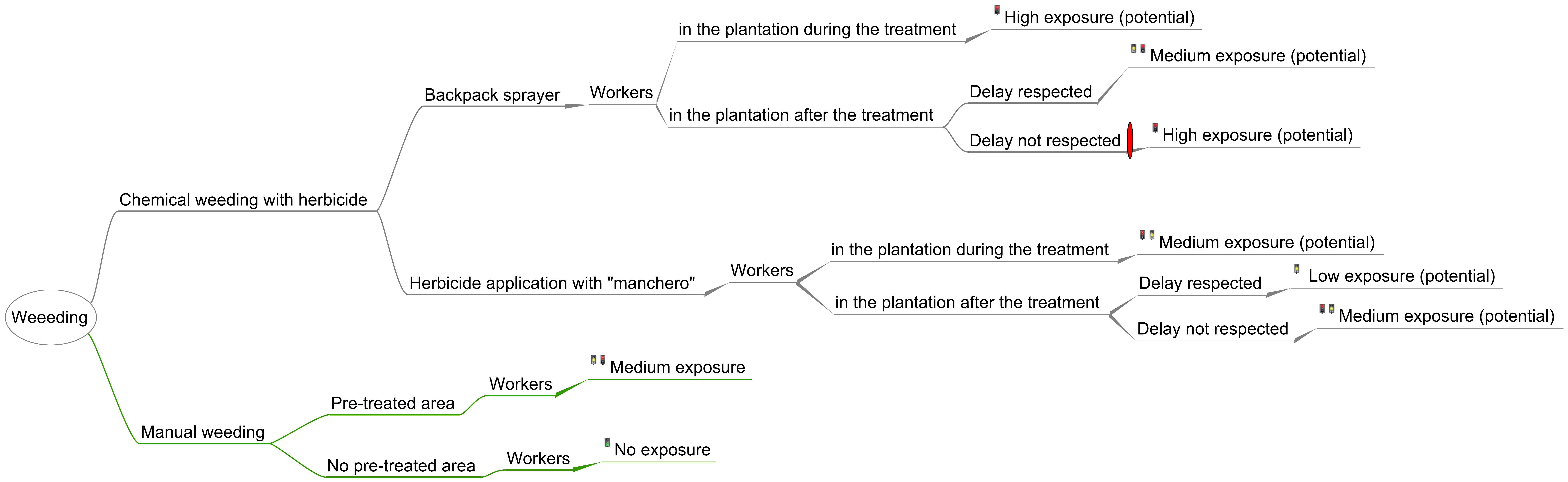

Fallowing
Manual herbicide application
Workers
in the plantation during the treatment
High exposure (potential)
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)
Manual cutting
Pre-treated area
Workers
Medium exposure
No pre-treated area
Workers
No exposure

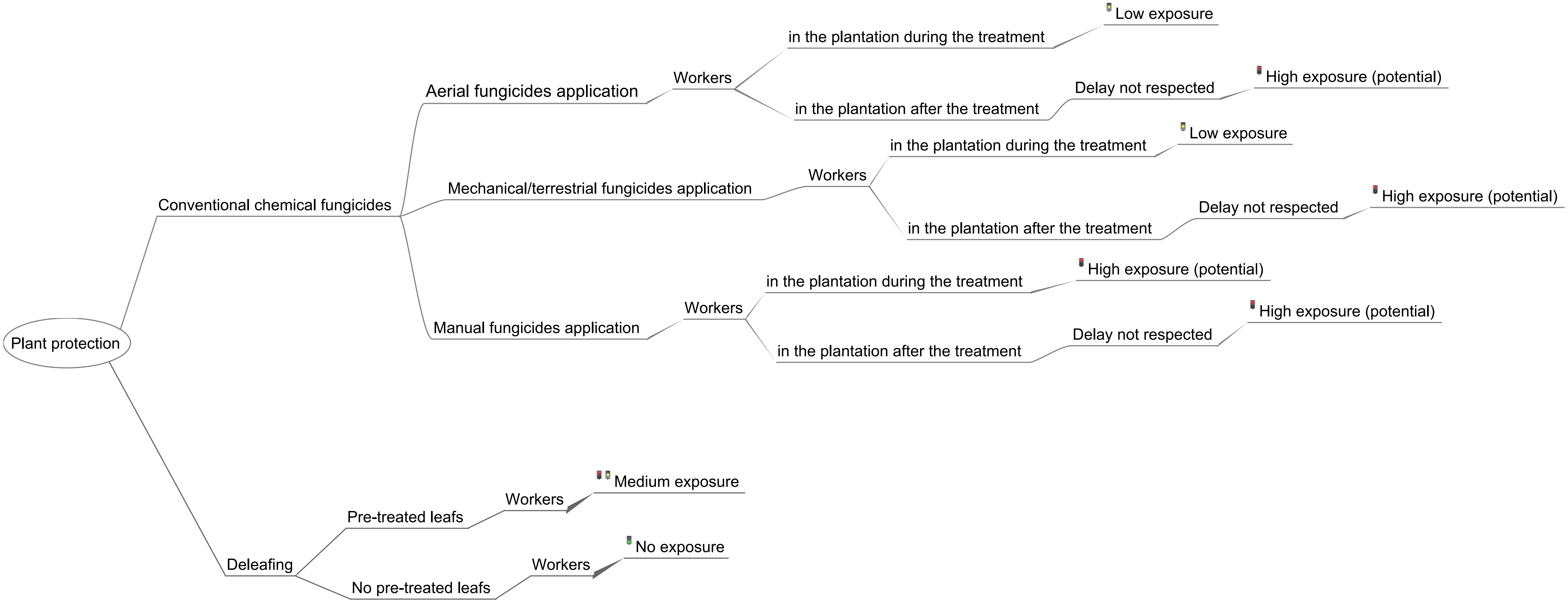

Weaning
Manual fungicide application
Workers
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)
Manual insecticide application
Workers
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)

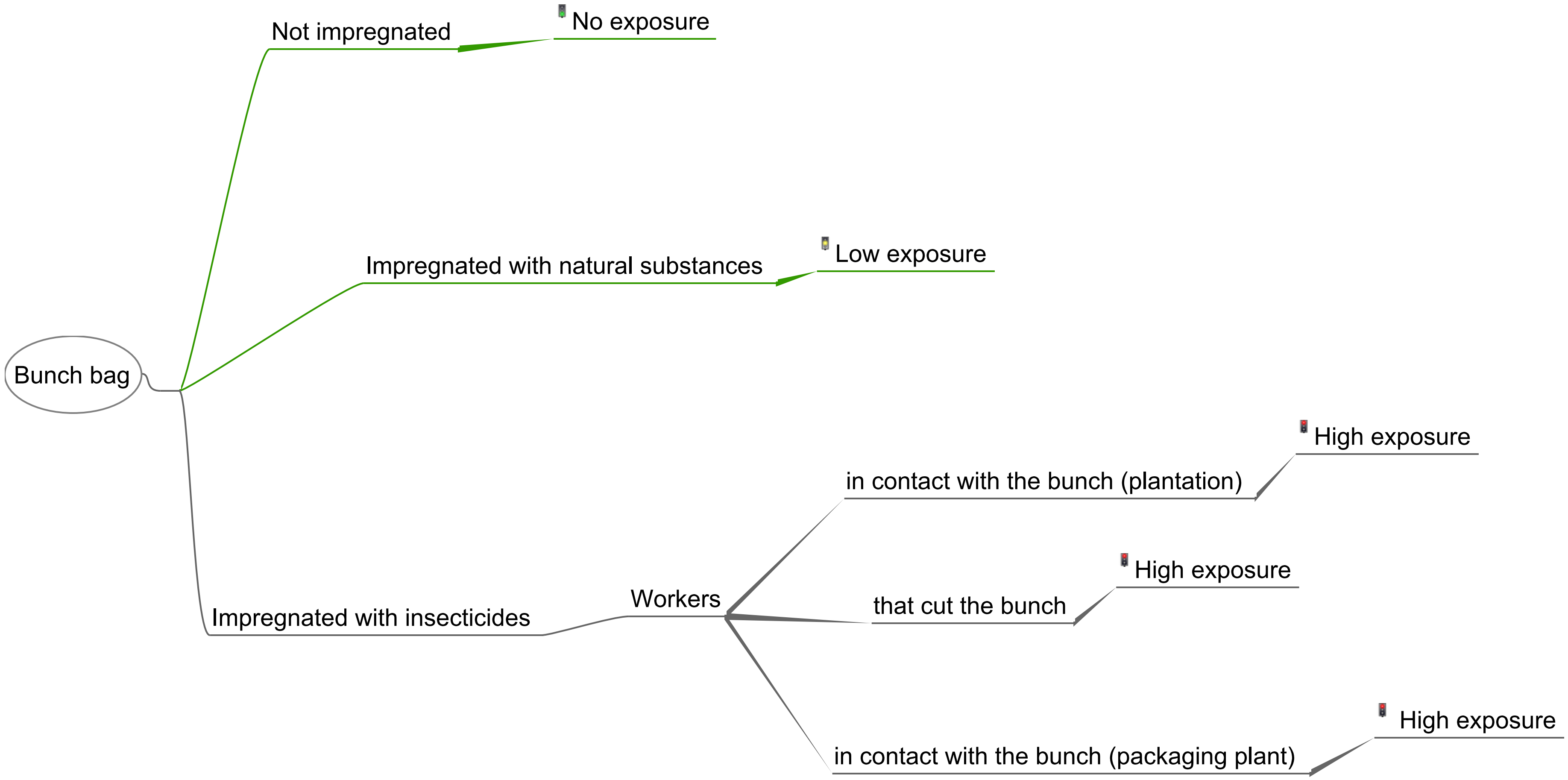

Shadehouse
Fungicide application
Manual fungicide application
Workers
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)
Aerial fungicide application
Workers
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)
Manual insecticide application
Workers
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)
Manual herbicide application
Workers
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)

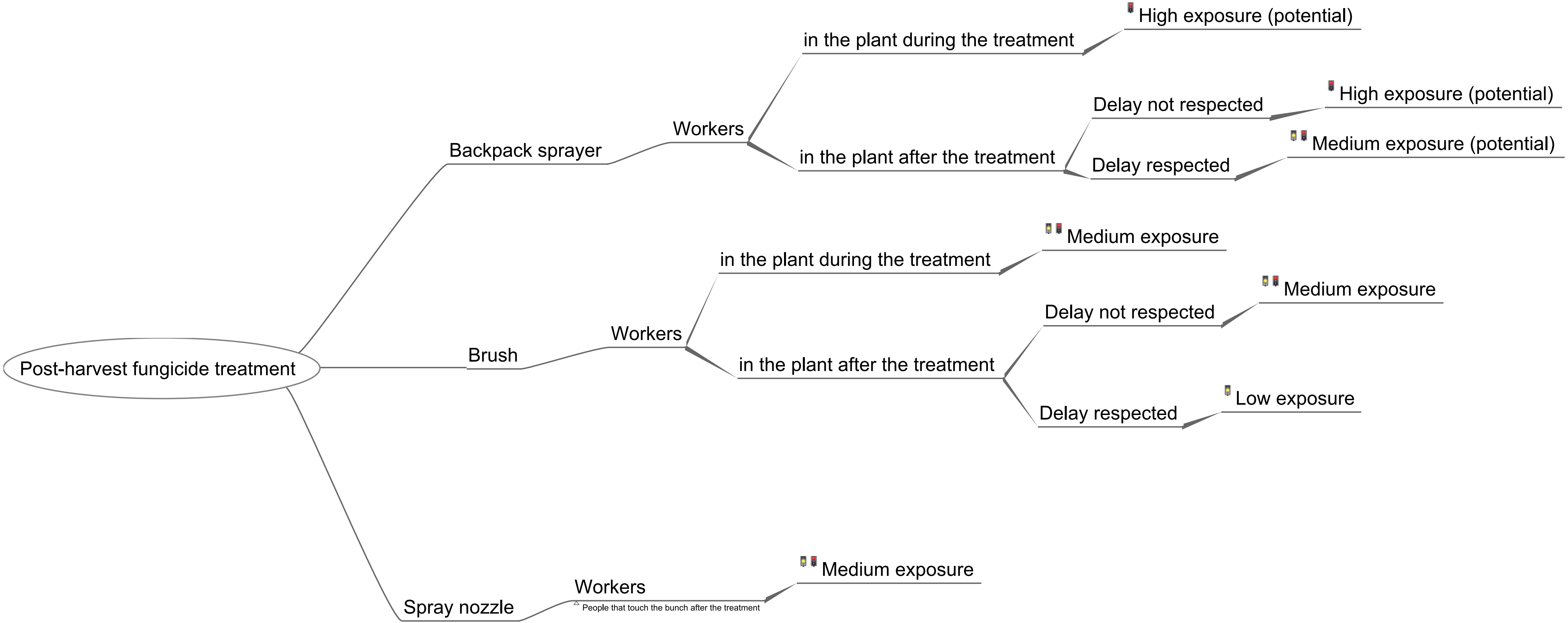


Fertilisation
Manual fertilization
Workers
in the plantation during the treatment
Low exposure (potential)
in the plantation after the treatment
Low exposure (potential)
Mechanical ferti-irrigation
Workers
in the plantation during the treatment
No exposure (potential)
in the plantation after the treatment
No exposure (potential)


Weeeding
Chemical weeding with herbicide
Backpack sprayer
Workers
in the plantation during the treatment
High exposure (potential)
in the plantation after the treatment
Delay respected
Medium exposure (potential)
Delay not respected
High exposure (potential)
Herbicide application with "manchero"
Workers
in the plantation during the treatment
Medium exposure (potential)
in the plantation after the treatment
Delay respected
Low exposure (potential)
Delay not respected
Medium exposure (potential)
Manual weeding
Pre-treated area
Workers
Medium exposure
No pre-treated area
Workers
No exposure


Plant protection
Conventional chemical fungicides
Aerial fungicides application
Workers
in the plantation during the treatment
Low exposure
in the plantation after the treatment
Delay not respected
High exposure (potential)
Mechanical/terrestrial fungicides application
Workers
in the plantation during the treatment
Low exposure
in the plantation after the treatment
Delay not respected
High exposure (potential)
Manual fungicides application
Workers
in the plantation during the treatment
High exposure (potential)
in the plantation after the treatment
Delay not respected
High exposure (potential)
Deleafing
Pre-treated leafs
Workers
Medium exposure
No pre-treated leafs
Workers
No exposure


Bunch bag
Not impregnated
No exposure
Impregnated with natural substances
Low exposure
Impregnated with insecticides
Workers
in contact with the bunch (plantation)
High exposure
that cut the bunch
High exposure
in contact with the bunch (packaging plant)
High exposure



Post-harvest fungicide treatment
Backpack sprayer
Workers
in the plant during the treatment
High exposure (potential)
in the plant after the treatment
Delay not respected
High exposure (potential)
Delay respected
Medium exposure (potential)
Brush
Workers
in the plant during the treatment
Medium exposure
in the plant after the treatment
Delay not respected
Medium exposure
Delay respected
Low exposure
Spray nozzle
Workers
People that touch the bunch after the treatment
Medium exposure