ANNEXES

I) Principales réglementations des OGM

Monde

- Organisation Mondiale du Commerce (OMC) : En l'absence de réglementation spécifique sur les OGM, plusieurs accords généraux concernent les OGM : Accord Général sur les tarifs douaniers et le commerce (GATT), Accord sur l'application des mesures sanitaires et phytosanitaires (SPS), Accords sur les obstacles techniques au commerce (OTC). Les questions sanitaires et environnementales ne sont que des exceptions au principe général de libre-échange : les Etats peuvent restreindre les importations d'OGM à condition de prouver scientifiquement les risques qu'ils posent.
- Codex Alimentarius : vise à une harmonisation des normes en matière de sécurité alimentaire, produit des normes internationales, des recommandations et des lignes directrices non contraignantes, dont certaines sont intégrées à certains accords de l'OMC et deviennent donc contraignantes. A produit divers rapports sur l'analyse des risques et leur évaluation, qui sont proches des principes de la régulation européenne.
- Protocole de Carthagène sur la prévention des risques biotechnologiques relatifs à la Convention sur la Diversité Biologique. Premier instrument légal international qui traite spécifiquement des aspects de la sécurité sanitaire et environnementale liés à l'utilisation des OGM et a pour objectif de garantir la sécurité lors du transfert, de la manipulation et de l'utilisation d'OGM susceptibles de présenter des effets défavorables sur la conservation et l'utilisation durable de la diversité biologique.

Union Européenne

- Directive 90/219/CEE de la Commission relative à l'utilisation confinée de micro-organismes génétiquement modifiés. Modifiée par la directive 98/81/CE, la directive a été étendue à l'usage confiné de tous les OGM.
- Directive 90/210/CEE de la Commission relative aux disséminations volontaires d'organismes génétiquement modifiés dans l'environnement (expérimentations en champs d'essais et commercialisation).
- Directive 98/95 de la Commission. Réglemente l'inscription des variétés végétales génétiquement modifiées dans un catalogue.
- Directive 2001/18 relative à la dissémination d'OGM dans l'environnement et abrogeant la directive 90/220/CEE du Conseil. Réglemente les « disséminations volontaires d'organismes génétiquement modifiés », c'est-à-dire les autorisations pour les expérimentations en plein champ (Partie B) et leur mise sur le marché en ce qui concerne la culture (Partie C).
- Directive 98/44 sur la protection juridique des inventions biotechnologiques. Les variétés végétales restent exclues des brevets. Consécration de la coexistence des régimes de brevets et de certificats d'obtention végétale.
- Décision 2002/623/EC de la Commission arrêtant les notes explicatives destinées à compléter l'annexe II de la directive 2001/18. Donne les lignes directrices d'évaluation des risques environnementaux.
- Décision 2002/811/EC de la Commission. Donne les lignes directrices sur le plan de surveillance (monitoring) post-commercialisation.
- Décision 2002/813/EC de la Commission. Impose au notifiant de soumettre un résumé du dossier (SNIF dossier) et organise l'échange d'information entre la Commission et les Etats Membres.
- Décision 2003/701/EC de la Commission. Impose au notifiant de rapporter à la Commission les résultats des disséminations.
- Règlement 1829/2003 du Parlement européen et du Conseil relatif aux denrées alimentaires et aliments pour animaux génétiquement modifiés (dit « *Aliment GM* »). Réglemente la commercialisation des OGM en tant qu'aliments pour la consommation humaine (*food*) ou pour l'alimentation du bétail (*feed*). Remplace le règlement 258/97

dit « Novel food » relatif aux nouveaux aliments qui consacrait le principe d'équivalence en substance. S'inscrit dans le cadre de la directive 2001/18 et du règlement 178/2002, législation générale en matière de sécurité alimentaire. Est complété par le règlement 641/2004 qui en fixe les modalités d'application.

- Règlement 1830/2003 dit règlement « *traçabilité et étiquetage* ». Réglemente la traçabilité des OGM et des dérivés alimentaires qui en contiennent ainsi que leur étiquetage. Impose aux opérateurs d'indiquer sur une étiquette que « ce produit contient des organismes génétiquement modifiés ».
- Recommandation 2003/556/EC de la Commission établissant des lignes directrices pour la coexistence des cultures.
- Recommandation 2004/787 de la Commission concernant les lignes directrices techniques en matière d'échantillonnage et de détection des OGM et des matières produites à partir d'OGM en tant que produits ou ingrédients de produits, dans le cadre du règlement 1830/2003.

D'après Mahieu et Nihoul (2005) et Schiffino et Varone (2006).

II) Exemple de guide d'entretien

(Modèle de guide d'entretien utilisé avec les chercheurs, étude de cas 'froment')

ma recherche	**Introduction sur ma recherche : problème/innovations,** point de départ : projet de blé GM résistant au fusarium, étude de la fusariose et de la septoriose **Explication du mode d'entretien** (liste de questions, questions ouvertes, prise de notes, enregistrement)
rôle	**Rôle** par rapport aux maladies cryptogamiques (fusariose, septoriose) ? (ex : conseils, tests variétés, avertissements, recherche, ...) **Quels projets de recherche ?** Quelle est l'origine du projet de recherche ? Quels sont vos **partenaires & financeurs** pour les recherches ? (filière, public, privés)
Stratégies de lutte	**Quelles sont les stratégies actuelles** de lutte par rapport aux maladies ? (Pratiques curatives et pratiques préventives ?) **Quelle est l'utilisation** réelle de ces moyens de lutte (Proportion des producteurs ? Évolution?) **Fongicides :** Efficacité contre fusariose et septoriose ? **variétés résistantes** : A partir de quand dit-on qu'une variété est résistante ? Quelles sont les variétés plantées aujourd'hui ? bases génétiques communes pour les différents cultivars ? Evolution des caractéristiques ? des ventes ? Quelles sont les raisons de **l'échec des variétés résistantes** ?
Innovations futures	Quelles sont les **pistes d'innovations futures** ? (à côté des plantes transgéniques, horizon 2010-2020) Quel est le **potentiel** de ces voies d'innovations pour résoudre le problème des maladies ? Qui fait de la **recherche** là-dessus en Belgique ? Quels résultats ? Exemples : mélanges variétaux, champignons antagonistes, résistance induite
Av/Inconv blés GM	Etes-vous au **courant des projets** de blés GM résistants au fusarium ? **Quels sont les avantages et inconvénients** de blés transgéniques (par rapport à l'amélioration classique) ? **Quels en seraient les impacts agronomiques, environnementaux et socio-éco ?**
Divers (Exemples de questions spécifiques à certains acteurs)	
Problèmes en céréales ?	Quels sont les problèmes majeurs en production de blé aujourd'hui ? Quelle est la place des maladies fongiques dans ceux-ci ?
Recherche	**Quelles sont les évolutions** de la recherche sur la lutte contre les maladies ?
Recherches socio-éco	Avez-vous **connaissance** de recherches sur les aspects socio-économiques ? (pourquoi les producteurs traitent plus que nécessaire, filières de qualité différenciée,…) Trouvez-vous cela **utile** ? Qui en fait en Belgique ? Y a-t-il par exemple des recherches pour vérifier si les c**onseils du Livre Blanc sont suivis ou non** (conseils pour la prévention et la protection fongicide raisonnée)

Filière ?	Est-ce que certaines filières poussent plus loin l'exigence de lutte que la réglementation nationale ? (Babyfood, pain Bayard?)
Fin entretien	Personnes à **rencontrer**,importantes dans le secteur et pour ces questions-là) ? **Documents** à lire (de votre organisation ou autre) ?

III) Liste des personnes interrogées

Remarques :

Sur le choix des personnes interrogées, voir les sections *4.A. Le système analysé* et *4.C.2. Enquête par entretiens* du Chapitre 2.

Dans le texte, des faux noms ont été utilisés afin d'éviter que ce travail interfère négativement sur les relations interpersonnelles des acteurs interrogés ou que chacun cherche davantage à savoir ce qui a été dit par chaque personne plutôt que de comprendre l'importance de l'extrait d'interview pour l'analyse systémique. Voici la liste des acteurs réellement interrogés.

A. *Etude de cas pommiers*

Acteurs économiques de la filière céréalière, y compris producteurs

Pierre van der Linden, producteur, Ferme d'Agbiermont.

Serge Fallon, producteur, Vergers de la Vallée..

Eric Jadoul, producteur à Vorsen.

Marc de Froidmont, producteur bio à Visé.

Pierre Arnauts, directeur commercial de la *Veiling Haspengouw* (criée).

Paul Van Laer, directeur commercial des pépinières *Jo Nicolaï*.

Florent Geerdens, directeur de *René Nicolaï Boomkwekerij* (pépinières).

Elena Grillet, responsable de la communication pour les variétés *Les Naturianes (France, par tél)*.

Recherche et Encadrement public des producteurs

Marc Fisher, ancien ingénieur horticole aux pépinières Jo Nicolaï.

André Sandrap, professeur d'horticulture retraité, rédacteur de la revue *Le Fruit Belge*.

Olivier Warnier, responsable du Centre Fruitier Wallon à Merdorp.

Marc Lateur, Chef de travaux du département Lutte biologique et ressources phytogénétiques du Centre de Recherches Agronomiques, Gembloux.

Charles de Schaetzen, responsable du département Service aux producteurs de la station expérimentale de Gorsem.

Jef Vercammen, responsable du Proefcentrum voor Fruitteelt (Proeftuin Pit- en Steenfruit).

Philippe Marc, conseiller technique et animateur du GAWI (Groupement d'Arboriculteurs pratiquant en Wallonie les techniques Intégrées)

Piet Creemers, président du département de mycologie de la station de Gorsem.

Wannes Keulemans et Marc Davey, responsable et chercheurs du Fruitteeltcentrum (KUL).

Professeur Tupy, obtenteur de la variété Topaz, station d'amélioration Střížovice, *(Tchécoslovaquie, par tél).*

Henk Schouten, scientifique membre de l'équipe de Plant Research International *(Pays-Bas, par tél).*

B. Etude de cas froment

Acteurs économiques de la filière céréalière, y compris producteurs

Christian Dieu (Agricogest, Agrival et Sogesa : sociétés de conseil en gestion agricole et entreprise agricole)

Alain Gérard (Responsable Semences, Société Coopérative des Agriculteurs de la Meuse (SCAM))

Marie-Christine Ducourouble (Sélectionneuse céréales, Etablissements V. Jorion et Fils)

Alex François (Moulin de Statte)

Benoit Goes (Arvensia, réseau européen de courtiers en grain)

Olivier Marchand (Responsable filière babyfood, Nestlé)

Michel Van Overberghe (Responsable Semences, Wal.Agri)

Encadrement public des producteurs et recherche

Bernard Bodson (Professeur, Faculté Universitaire de Sciences Agronomiques, Unité de Phytotechnie des régions tempérées)

Xavier Bertel (coordinateur du CADCO (Centre Agricole pour le Développement des Cultures Céréalières et Oléo-protéagineuses)

Anne Chandelier (Attaché scientifique, CRA-W, Département Lutte biologique et Ressources phytogénétiques, Section Mycologie)

Luc Couvreur (Attaché scientifique, CRA-W, Département Productions Végétales, Section Obtentions végétales) (Deux interviews)

Adrien Dekeyser (Attaché scientifique Céréales, CRA-W, Département Lutte biologique et Ressources phytogénétiques, Section Céréales)

Jean-Pierre Destain (Président, Filière Wallonne Grandes Cultures)

Moussa El Jarroudi (Chercheur doctorant, Université de Liège, Département Sciences et gestion de l'Environnement)

André Falisse (Professeur, Faculté Universitaire de Sciences Agronomiques, Unité de Phytotechnie des régions tempérées)

Thierry Hance (Professeur, Université catholique de Louvain, Unité d'Ecologie et de biogéographie)

Jean-Luc Herman (Attaché scientifique, CRA-W, Département Productions Végétales, Section Obtentions végétales)

Jean-Marie Jacquemin (Directeur scientifique, CRA-W, département Biotechnologie)

Henry Maraite (Professeur, Université catholique de Louvain, Unité de Phytopathologie)

Jean Marot jr. (Ingénieur, Secrétariat du Comité Régional Phyto, UCL - AGRO - Unité de Phytopathologie)

Jean-Marc Moreau (Attaché scientifique, CRA-W, Département Phytopharmacie, Fongicides et maladies des plantes)

Louis van Eylen (ex-Ministère Agriculture, catalogue des variétés)

Thierry Walot (Chercheur, Université catholique de Louvain et GIREA, Groupe Interuniversitaire de Recherches en Ecologie Appliquée)

Acteurs hors filière mais liés à l'agriculture

Lionel Delvaux (Attaché « Ruralité », Inter-Environnement Wallonie, Cellule Environnement)

Entretiens complémentaires (recherche ou complément d'informations, par téléphone)

Françoise Bedoret (Direction générale de l'Agriculture, Direction Qualité des produits) : inscription au catalogue des variétés

Mr Brasseur (Moulins de Statte) : variétés pour le Pain Bayard

Adrien Dekeyser (Attaché scientifique Céréales, CRA-W, Département Lutte biologique et Ressources phytogénétiques) : complément à interview complet (variétés, itinéraires techniques et optimum économique)

David Dos Santos (Direction générale de l'Agriculture, Direction Qualité des produits) : triage des semences

Bruno Lefrancq (Attaché scientifique, CRA-W, département Lutte biologique et Ressources phytogénétiques, Section fruitier) : recherche sur résistance systémique induite en céréales

Jean-Marc Moreau (Attaché scientifique, CRA-W, Département Phytopharmacie, Fongicides et maladies des plantes) : complément à interview complet (fongicides et optimum économique)

Yvan Polet (Ancien sélectionneur chez Jorion (récemment) et Haton (biotechnologies jusqu'en 90) : acteurs commerciaux et sélection

Caroline Schollaert (Direction générale de l'Agriculture, Direction Qualité des produits) : multiplication des variétés et semences

Synagra (Secrétariat) : refus de lots dépassant les seuils de mycotoxines

Jean Wart (Responsable collecte et semences, Société Coopérative des Agriculteurs de la Meuse (SCAM)

C. *Gestion de l'innovation dans les filières (Chapitre 5)*

Entretiens complets

Thierry Hance, Professeur (lutte biologique), Unité d'Ecologie et de biogéographie, Université catholique de Louvain, 15 février 2005

Josy Flaba, Direction du Développement et de la Vulgarisation, Division de la Recherche, du Développement et de la Qualité (DGA-IG3), Direction Générale de l'Agriculture de la Région Wallonne (DGA-IG3), 14 décembre 2005

Anne Pourtois, Conseiller scientifique (Secteur végétal), Direction de la Recherche, Division de la Recherche, du Développement et de la Qualité (DGA-IG3), Direction Générale de l'Agriculture de la Région Wallonne, 18 novembre 2005

Marc Van Heuckelom et Christine Mathieu, Service Programmes de Recherche (SPP) Politique scientifique fédérale, 2 décembre 2005

André Goffeau, ex-haut fonctionnaire, longue expérience dans le pilotage des programmes biotechnologies et biologie moléculaire à la DG Recherche de la Commission Européenne, Prof extraordinaire émérite UCL, 22 novembre 2005

Richard Hardwick, haut fonctionnaire retraité, longue expérience à la DG Recherche de la Commission Européenne, 4 juillet 2006

Entretiens par téléphone

Firouz Kabiri, Entreprise Biotop (lutte biologique) 29 février 2006

Vincent Cambier, Entreprise Viridaxis, 28 février 2006

Monsieur Zechendorf, bibliothécaire « Biotechnologies », DG Recherche de la Commission Européenne, 4 juillet 2006

IV) Analyse du Livre Blanc (Chapitre 4)

Tableau 1 : Thèmes des articles structurels (présents dans chaque édition) et conjoncturels du Livre Blanc (2000-2005).

Thèmes	Articles		Pages	
	#	%	#	%
ARTICLES STRUCTURELS	**82**	**66%**	**1216**	**83%**
Phytotechnie des céréales	36	29%	729	50%
froment	12	10%	468	32%
escourgeon et orge d'hiver	12	10%	190	13%
orge brassicole	12	10%	71	5%
Fumure	21	17%	239	16%
fractionnement de la fumure (évolution de)	7	6%	68	5%
azote minéral du sol	7	6%	28	2%
fumure azotée des céréales	7	6%	143	10%
Désherbage céréales	7	6%	82	6%
Fongicides	6	5%	80	5%
Climatologie	6	5%	34	2%
Qualité du froment	6	5%	52	4%
ARTICLES CONJONCTURELS	**43**	**34%**	**249**	**17%**
Maladies, ravageurs et dégâts	15	12%	93	6%
Variétés de froment et maladies	2	2%	14	1%
Fusariose et Myxotoxines	3	2%	39	3%
Piétin-échaudage (traitement des semences)	1	1%	4	0%
Mosaïques	2	2%	7	0%
Jaunisse nanisante (validation des avertiss)	2	2%	11	1%
Ravageurs (limaces)	2	2%	5	0%
Pucerons	1	1%	4	0%
Mouches	1	1%	5	0%
Dégâts d'hiver	1	1%	4	0%
Nouveautés et divers	11	9%	50	3%
Perfectionnement semoirs	1	1%	2	0%
Semis sans labour	0	0%	0	0%
Maïs sous plastic	1	1%	7	0%
Variétés alt. et de printemps	1	1%	4	0%
Epeautre	2	2%	10	1%
Froments hybrides	1	1%	5	0%
Fumure organique	1	1%	7	0%
Paille	1	1%	7	0%
Compaction des sols	1	1%	4	0%
Froment en agriculture biologique	2	2%	4	0%
Mesures agri-environnementales	6	5%	28	2%
Valorisation des céréales	5	4%	38	3%
Froment aliment pour le poulet	2	2%	12	1%
Valorisation céréales immatures	1	1%	11	1%
Amidon du grain	1	1%	9	1%

Blés de qualité	1	1%	6	0%
Contexte politique	2	2%	15	1%
Réforme de la PAC	1	1%	10	1%
Produits de protection des plantes (normes)	1	1%	5	0%
Impact environnemental	4	3%	25	2%
Reduction d'intrants	1	1%	8	1%
Pollution des eaux	2	2%	9	1%
Exotoxicologie (toxicité pesticides)	1	1%	8	1%
Annexes	2		318	
Pages vertes - info générales : reportées dans les thèmes	2		4	
Pages jaunes - herbicides, antiverse, fongicides, insecticides, traitemengt des semences, variétés des différentes céréales, stades repères de la végétation, calendrier des travaux	0		314	
TOTAL (sans annexes)	**125**	**100%**	**1465**	**100%**

Tableau 2 : Détail, année par année, du tableau 20. Analyse des thèmes des articles parus dans le Livre Blanc (2000-2005) Les thèmes soulignés sont ceux pour lesquels le contenu des articles a été analysé au niveau du type de recherches expérimentale

Années	fev 2000		sept-00		fev 2001		sept-01		fev 2002		sept-02		fev 2003		sept-03		fev 2004		sept-04		fev 2005		sept-05		TOTAL			
Thèmes	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	# art	# pages	% (articles)	% (pages)
ARTICLES STRUCTURELS																									82	1216	66%	83%
Phytotechnie des céréales																									36	729	29%	50%
froment	1	56	1	16	1	46	1	20	1	60	1	22	1	53	1	27	1	58	1	25	1	60	1	25	12	468	10%	32%
escourgeon et orge d'hiver	1	21	1	7	1	17	1	5	1	21	1	10	1	21	1	14	1	22	1	14	1	22	1	16	12	190	10%	13%
orge brassicole	1	6	1	4	1	7	1	5	1	8	1	4	1	8	1	4	1	8	1	4	1	7	1	6	12	71	10%	5%
Fumure																									21	239	17%	16%
fractionnement de la fumure (évo	1	20			1	7			2	12			1	8			1	10			1	11			7	68	6%	5%
azote minéral du sol	1	3			1	4			1	2			2	15			1	2			1	2			7	28	6%	2%
fumure azotée des céréales	2	15			1	25			1	25			1	26			1	26			1	26			7	143	6%	10%
Désherbage céréales	1	4	1	10	1	26	1	13	1	7	1	8					1	14							7	82	6%	6%
Fongicides	1	8			1	19			1	8			1	15			1	17			1	13			6	80	5%	5%
Climatologie	1	4			1	6			1	6			1	6			1	6			1	6			6	34	5%	2%
Qualité du froment			1	9			1	4			1	9			1	9			1	12			1	9	6	52	5%	4%
ARTICLES CONJONCTURELS																									43	249	34%	17%
Maladies, ravageurs et dégâts																									15	93	12%	6%
Variétés de froment et maladies									1	8							1	6							2	14	2%	1%
Fusariose et Myxotoxines													1	23			1	5			1	11			3	39	2%	3%
Piétin-échaudage (traitement des semences)															1	4									1	4	1%	0%
Mosaïques							1	3													1	4			2	7	2%	0%
Jaunisse nanisante (validation des avertiss)															1	6							1	5	2	11	2%	1%
Ravageurs (limaces)			1	3			1	2																	2	5	2%	0%
Pucerons																			1	4					1	4	1%	0%
Mouches	1	5																							1	5	1%	0%
Dégâts d'hiver															1	4									1	4	1%	0%
Nouveautés et divers																									11	50	9%	3%
Perfectionnement semoirs																			1	2					1	2	1%	0%
Semis sans labour																									0	0	0%	0%
Maïs sous plastic							1	7																	1	7	1%	0%
Variétés alt. et de printemps																	1	4							1	4	1%	0%
Epeautre	1	6					1	4																	2	10	2%	1%
Froments hybrides	1	5																							1	5	1%	0%
Fumure organique					1	7																			1	7	1%	0%
Paille																					1	7			1	7	1%	0%
Compaction des sols																			1	4					1	4	1%	0%
Froment en agriculture biologique							1	2			1	2													2	4	2%	0%
Mesures agri-environnementales			1	4			1	3			1	4	1	7	2	10									6	28	5%	2%
Valorisation des céréales																									5	38	4%	3%
Froment aliment pour le poulet													1	6			1	6							2	12	2%	1%
Valorisation céréales immatures																			1	11					1	11	1%	1%
Amidon du grain																	1	9							1	9	1%	1%
Blés de qualité																					1	6			1	6	1%	0%
Contexte politique																									2	15	2%	1%
Réforme de la PAC																					1	10			1	10	1%	1%
Produits de protection des plantes (normes)									1	5															1	5	1%	0%
Impact environnemental																									4	25	3%	2%
Reduction d'intrants	1	8																							1	8	1%	1%
Pollution des eaux					1	4											1	5							2	9	2%	1%
Exotoxicologie (toxicité pesticides)					1	8																			1	8	1%	1%
Annexes																									2	318		
Pages vertes - info générales : reportées dans les thèmes																	1	2			1	2			2	4		
Pages jaunes - herbicides, antiverse, fongicides, insecticides, traitemengt des semences, variétés des différentes céréales, stades repères de la végétation, calendrier des travaux		55				55				55				55				47				47			0	314		
TOTAL (sans annexes)	14	216	7	53	12	231	11	68	12	217	7	59	12	243	9	78	16	247	8	76	14	234	5	61	125	1465	100%	100%

V) Facteurs techniques influençant le développement des voies d'innovation (Chapitre 4)

Tableau 3 : Facteurs techniques (positifs et négatifs) agissant sur le développement scientifique des voies d'innovations (voies principales).

Voies principales	Tavelure du pommier	Fusariose du froment
Phytopharmacie		- contrainte de devoir traiter à une période précise et très courte - résistances des *Fusarium* aux fongicides
Amélioration variétale		+ existence de nouvelles sources de résistances dans des variétés étrangères, qui sont en cours d'intégration dans les programmes d'amélioration variétale + stabilité de la résistance variétale des meilleurs cultivars résistants (contrairement aux autres maladies pour lesquelles les résistances sont souvent susceptibles d'être peu durables) [litt] + avantages techniques des outils liés aux biotechnologies (augmentation de la précision, diminution du risque d'erreur) - le contrôle des résistances aux maladies est polygénique (mais existence de QTL majeurs dans le cas de la fusariose ce qui rend l'obtention de variétés résistantes plus complexe) - de nombreux caractères agronomiques indésirables dans les sources de résistances de FHB - la taille du génome : le génome du blé est beaucoup plus grand que celui du riz, qui a été décodé, ce qui rend plus complexe son décodage - effet de l'environnement sur le phénotype de résistance
Ingénierie génétique		+ Extension du domaine de recherche de sources de protéines anti-Fusarium à des plantes autres que les céréales, aux insectes, aux bactéries, champignons, etc + Possibilité de combiner des résistances provenant des cultivars issus de l'amélioration conventionnelle à celles obtenues par transgénèse - faible efficacité des méthodes de transformation (régénération des plantes, variation somaclonale,…) - problème d'héritabilité du transgène - problème de stabilité d'expression du transgène - choix de la protéine à propriété antifongique et du promoteur - interactions négatives entre différents mécanismes de défense - doutes sur la durabilité de la résistance obtenue

Tableau 4 : Facteurs techniques (positifs et négatifs) agissant sur le développement scientifique des voies d'innovations (voies secondaires)

Voies secondaires	Tavelure du pommier	Fusariose du froment
Diversité génétique de la culture (vergers diversifiés ou mélanges variétaux)	+ potentiel théorique de réduction des maladies - choix des variétés (floraison, date récolte, nécessité de protection phyto)	+ potentiel théorique de réduction du risque de maladies + augmentation de la stabilité des rendements - choix de la composition du mélange - nécessité de faire des essais de grande taille pour diminuer l'effet de l'inoculum extérieur - spécificités de chaque maladie
Champignons antagonistes	- différence serre/champ	+ existence d'agents antagonistes des Fusarium spp. (bactéries, champignons,…) - faibles connaissances sur l'effet précis de l'inoculation des débris végétaux - difficultés techniques pour l'application de ces principes aux maladies cryptogamiques
Eliciteurs de résistance systémique induite	- milliers de molécules à tester	+ potentiel théorique de réduction du risque de maladies + plus faible propension à générer des populations de pathogènes résistants que les fongicides systémiques - mauvais résultats des produits récemment mis en vente - coûts d'adaptation de la plante (fitness costs) - conflits dans les voies de défense signalées par l'acide jasmonique et l'acide salicylique - érosion progressive de l'efficacité(adaptation des pathogènes comme dans le cas d'une résistance horizontale)

Tableau 5 : Facteurs socio-économiques et politiques (positifs et négatifs) agissant sur le développement scientifique des voies d'innovations (Voies secondaires)

Voies d'innovations (secondaires)	Tavelure du pommier	Fusariose du froment
Champignons antagonistes	- droit de propriété intellectuelle (ex du Canada)	- difficultés des procédures d'autorisations des agents de contrôle biologique
Eliciteurs de résistance systémique induite	- produits actuels non concurrentiels par rapport aux fongicides de synthèse - recherche à un stade fondamental - faibles efforts de recherche appliquée	+ facilitation des procédures réglementaires d'autorisation de ces produits + meilleure acceptation par le public et les agriculteurs - produits actuels non concurrentiels par rapport aux fongicides de synthèse - recherche à un stade fondamental - faibles efforts de recherche appliquée

VI) Eléments macroéconomiques et dynamiques : contexte actuel et évolutions possibles (Chapitre 5)

Tableau 6 : Eléments macro-économiques (comparaison) et possibilités de changement 2005-2020

Type	Pomme	Froment
Eléments caractérisant le contexte		
Macro-Economiques	▪ Prix bas (diminution des prix) ▪ Crises des variétés en Belgique (remplacer Jonagold et ses mutants) ▪ Développement de 'clubs' (intégration verticale dans la filière) ▪ Concentration de la production dans des régions fruitières (dans toute l'Europe) ▪ Mondialisation des marchés (forte concurrence avec les nouveaux pays exportateurs dans l'hémisphère Sud) ▪ Distinction des acteurs innovateurs en matière d'amélioration variétale et de phytopharmacie ▪ Surproduction structurelle au niveau mondial	▪ Prix bas (diminution des prix) ▪ Importance croissante des qualités technologiques (taux protéines, etc) ▪ Alliances firmes 'intermédiaire généraliste avec les producteurs' et firmes semencières (intégration verticale dans la filière) ▪ Production dans bassins céréaliers et dispersée dans la plupart des régions ▪ Mondialisation des marchés (mais large proportion des céréales ne sont pas échangées au niveau international) ▪ Intégration (mêmes acteurs innovateurs en matière d'amélioration variétale et de phytopharmacie) ▪ Importance croissante de la traçabilité et de la sécurité alimentaire
Tendances possibles		
Macro-Economiques	▪ Hausse de la demande suite à une modification potentielle des comportements alimentaires (augmentation souhaitable de la consommation de fruits)	▪ Evolution du prix des céréales (maintien de prix bas) ▪ Développement des systèmes à bas-intrants utilisant des variétés rustiques ▪ Evolution de l'utilisation des céréales (énergies vertes,..)
Environnementales	▪ Fréquence plus élevée d'extrêmes climatiques (sécheresse, humidité et chaleur, etc)	▪ Fréquence plus élevée d'extrêmes climatiques (sécheresse, humidité et chaleur, etc) ▪ Conditions épidémiologiques (nouveaux types de pathogènes et de problèmes liés à ceux-ci : dégâts aux cultures, fusariotoxines,…)
Innovations agronomiques	▪ Commercialisation de variétés plus résistantes, de nouveaux produits phytopharmaceutiques ou de variétés transgéniques	
Politiques	▪ Exigences plus sévères en matière de résidus de pesticides sur les fruits ▪ Réglementations plus contraignantes en matière de pesticides (réduction de l'utilisation et homologation des produits)	▪ Introduction de normes maximales en matière de mycotoxines (niveau UE) ▪ Introduction de normes minimales de résistance variétale à la fusariose ▪ Réglementations plus contraignantes en matière de pesticides (réduction de l'utilisation et homologation des produits) ▪ Exigences de traçabilité des matières premières agricoles ▪ Modifications de la politique agricole commune (découplage, …)

VII) Observation participante : liste des forums publics et scientifiques sur les OGM et sur la recherche et l'innovation scientifique en agriculture

A. *Niveau régional (Chapitre 5)*

Date	Nom	Organisateur	Type	Lieu	Niveau (RW, B, UE, Int)
2003	Etats Généraux de l'Agriculture (7 mars)	Ministre de l'Agriculture et de la ruralité de la Région Wallonne	Journée-conférence	Gembloux	RW
2004	*56th International Symposium on Crop Protection (May 4)*	Universiteit Gent	Congrès scientifique	Gand	international
2004	*Systèmes agricoles et développement durable et recherche-intervention (22 juin)*	*CRA-W et ULG-SEED*	Workshop scientifique	Libramont	RW
2004	Groupe de travail sur la coexistence en cultures de betteraves (25 juin)	RW-DGA	Réunion de travail	Namur	RW
2004	*European agriculture in a global context. VIII European Society of Agronomy Congress* (11-15 July).	*European Society of Agronomy*	Congrès scientifique	Copenhagen	UE et International
2005	Sensibilisation à un usage durable des pesticides (26 janvier)	Projet PADDII (UG, UCL, Cerva)	Après-midi d'études	LLN	RW
2005	*Lutte intégrée ou biologique en arboriculture fruitière (14 décembre)*	Région Wallonne – DG Agriculture	Après-midi d'études	Namur	RW
2005	*Pesticides, agriculture et environnement. Réduire l'utilisation des pesticides et limiter leurs impacts environnementaux. Expertise scientifique collective (15 décembre)*	INRA-Cemagref	Colloque de restitution de l'expertise collective	Paris	France
2006	Forum Agriculture Durable (18 mai)	Politique Scientifique (Cluster Agriculture durable)	Journée acteurs-chercheurs	Bruxelles	Bel
2006	58th International Symposium on Crop Protection (23 mai)	UG	Colloque scientifique	Gand	UE
2006	Biotechnologies : Défis économiques et visions de la société (7 juin)	Association Belge d'Economie Rurale (ABER)	Journée d'études	Bruxelles	B-UE-Int

B. Niveau national et européen (Chapitre 7)

Date	Nom	Organisateur	Type	Lieu	Niveau (RW, B, UE, Int)
2002	*OGM. Comment réduire les risques ? (24 avril)*	*Alliances pour le développement durable (Ecolo)*	Journée-Conférence	Gembloux	RW-B-UE
2002	*Communes et OGM. Les arguments du choix (6 novembre)*	*CRA et FUSA*	Journée d'information et de débat	Gembloux	RW
2003	*Towards Sustainable Agriculture for Developing Countries: options from life sciences and biotechnologies, Discussion platform (30-31 January)*	*European Commission*	2 Journées-conférence	Bruxelles	International
2003	Plantes transgéniques : risques pour l'écosystème et l'agriculture, par Philippe Baret, dans le cadre du séminaire « Les Organismes génétiquement modifiés : entre science et société » (7 février)	UCL-CITES	Séminaire scientifique	LLN	-
2003	La régulation publique des OGM, par N Schiffino, dans le cadre du séminaire « Les Organismes génétiquement modifiés : entre science et société » (14 février)	UCL-CITES	Séminaire scientifique	LLN	B - UE
2003	Risque et expertise, par F. Dassetto, dans le cadre du séminaire « Les Organismes génétiquement modifiés : entre science et société » (28 février)	UCL-CITES	Séminaire scientifique	LLN	-
2003	Etats Généraux de l'Agriculture (7 mars)	Ministre de l'Agriculture et de la ruralité de la Région Wallonne	Journée-conférence	Gembloux	RW
2003	Valeurs et conservation de la biodiversité, par P. Joly (9 mars)	UCL-BDIV-Chaire Tractebel	Conférence	LLN	-
2003	*Essai d'interprétation d'une controverse socio-technique : le cas des OGM, par S Lavelle et P. Goujon*, dans le cadre du séminaire « Les Organismes génétiquement modifiés : entre science et société » *(14 mars)*	UCL-CITES	Séminaire scientifique	LLN	-
2003	*Droits de propriété intellectuelle et*	UCL-CITES	Séminaire scientifique	LLN	-

	brevetabilité, par N De Saedeleer, dans le cadre du séminaire « Les Organismes génétiquement modifiés : entre science et société » *(19 mars)*				
2003	*Mise en perspectives : enjeux épistémologiques et sociétaux, par Bernard Feltz*, dans le cadre du séminaire « Les Organismes génétiquement modifiés : entre science et société » *(21 mars)*	UCL-CITES	Séminaire scientifique	LLN	-
2003	*Contexte international OGM, par M. Deboyser (DG SANCO) (24 mars)*	UCL-CDRC	Conférence	LLN	UE et international
2003	*Risks and Opportunities in the biotechnology era*, European Parliement The 1st *Scientific and Technological options Assessment (*STOA) Annual Lecture, by Kary Mullis; Nobel Peace Prize (25 mars)	*European Parliement, (STOA)*	Conférence	Bruxelles	International
2003	*Earth Democracy : The World Beyond Corporate Globalisation*, by Vandana Shiva (7 avril)	UCL-CITES	Conférence scientifique	LLN	International
2003	Quel avenir alimentaire pour le monde, par Marcel Mazoyer (8 avril)	CETRI	Conférence	LLN	International
2003	Des OGM au champ ? Journée d'échanges avec les personnes-ressources et de débat public organisée dans le cadre du panel citoyen (12 avril)	FGF	Journée-conférence	Gembloux	RW-B
2003	OGM : De la contestation aux alternatives (20-21 juin)	L'Ecologiste	Colloque	Paris	International
2003	*Quelle gestion de l'innovation technologique : les discours des fonctionnaires européens au travers du débat sur les OGM ?, par Olivier Delaive (24 novembre)*	UCL-ANSO	Séminaire	LLN	UE
2003	*Risk perception : Science, Public Debate and Policy Making (4-5 décembre)*	European Commission	2 Journées-conférence	Bruxelles	UE
2003	The ecological economics of biodiversity, by Robert Costanza (15 décembre)	UCL-BDIV	Conférence scientifique	LLN	International
2003	Séminaire bisannuel des chercheurs du	PAI « The loyalties of knowledge » (ULB,	Workshop scientifique	Bruxelles	-

	réseau de recherche du PAI « *The loyalties of knowledge* » (17 décembre)	VUB, UG, Ecole des Mines de Paris)			
2003	Discussion meeting on *GM crops, modern agriculture and the environment*. (11 February)	The Royal Society	Journée -conférence	London	UK
2003	GMOs Co-existence or contamination ? *(28 mai*)	The Greens, FoE, Heinrich Böll Foundation	Journée -conférence	Bruxelles	UE
2004	*Risk assessment as a blackbox. Réunion GT OGM (28 janvier)*	PAI « The loyalties of knowledge » (ULB, VUB, UG, Ecole des Mines de Paris)	Réunion de travail	Bruxelles	-
2004	*Governance of Biodiversity as a Global Public Good : Bioprospection, Intellectural property Rights and Traditional Knowledge (5-6 February)*	*UCL-CPDR*	Workshop scientifique	LLN	International
2004	*De l'utopie écologiste au développement durable : le rôle de la biodiversité dans une planète en crise, par J. Blondel (10 février)*	*UCL-BIODIV-Chaire Tractebel*	Conférence	LLN	International
2004	Les aliments fonctionnels. Concept scientifique et stratégie de développement (13 février)	UCL-CITES	Séminaire scientifique	LLN	-
2004	L'érosion des sols en Belgique, par J Poesen (26 février)	ULB	Conférence	Bruxelles	Bel , UE et nternational
2004	Agri-culture : Reconnecting People, Land and Nature(3 mars)	KUL - CABME	Conférence scientifique	Leuven	International
2004	Assessing sustainability, by E. Mathijs, (10 mars)	Séminaires AgEcon	Séminaire scientifique	Bruxelles	-
2004	Les scénarios de sortie des OGM, par B Hériard et JC Dissart (12 mars)	UCL-CITES	Séminaire scientifique	LLN	UE
2004	*OMC et aliments, par Henry Culot (26 mars)*	UCL-CITES	Séminaire scientifique	LLN	International
2004	*Symposium Biodiversity : state, stakes and futures (8 avril)*	UCL-BIODIV	Symposium scientifique	LLN	-
2004	*56th International Symposium on Crop Protection (May 4)*	Universiteit Gent	Congrès scientifique	Gand	international
2004	*Evaluation du colza MSS & RF3 de Bayer en*	PAI « The loyalties of knowledge »	Séminaire scientifique	Bruxelles	Bel

	Belgique, par Sébastien Denys (7 juin)				
2004	Réunion de travail portant entre autres sur la rédaction d'un rapport sur les biotechnologies (13 mai)	FAO-Interdepartemental Working Group on Biotechnologies	Réunion de travail	Rome	International
19 -	*Systèmes agricoles et développement durable et recherche-intervention (22 juin)*	*CRA-W et ULG-SEED*	Workshop scientifique	Libramont	RW
2004	Groupe de travail sur la coexistence en cultures de betteraves (25 juin)	RW-DGA	Réunion de travail	Namur	RW
2004	*European agriculture in a global context. VIII European Society of Agronomy Congress* (11-15 July).	*European Society of Agronomy*	Congrès scientifique	Copenhagen	UE et International
2004	*Science, Ethics and Society, 5th Congress of the European Society for Agricultural and Food Ethics* (September 2-4)	*European Society for Agricultural and Food Ethics*	Congrès scientifique	Leuven	UE et International
2004	Journée OGM : Evolution du droit international, européen et belge (30 novembre 2004)	SPF Santé publique et sécurité de la chaîne alimentaire	Journée-conférence	Bruxelles	B, UE et International
Quelle protection juridique contre les risques des OGM ? par Stéphanie Mahieu (28 septembre 2004)	UCL-ETES	Séminaire	LLN	LLN	UE
2004	Quels sont les arguments rationnels contre les OGM ? par Marc Van Montagu (5 octobre)	UCL-UDA	Conférence grand public	LLN	International
2004	*Keep Europe GM-free ! Science for a GM free Sustainable Europe* (20 octobre)	ISIS, ISP, TWN	Journée-conférence	Bruxelles	UE
2004	Testing expertise (21 octobre)	PAI « The loyalties of knowledge » (ULB, VUB, UG, Ecole des Mines de Paris).	Colloque scientifique	Bruxelles	-

2004	Gouvernance internationale et développement durable, Conférence inaugurale, par L. Tubiana (8 décembre)	UCL-CITES-Chaire Tractebel	Conférence scientifique	LLN	International
2004	Le principe de précaution, entre souveraineté et coordination, par Olivier Godart (16 décembre)	UCL-CITES-Chaire Tractebel	Conférence scientifique	LLN	-
2004	Les brevets à l'Université, par G.Capart et B. Remiche (21 décembre)	UCL-ETES	Conférence	LLN	-
2005	Sensibilisation à un usage durable des pesticides (26 janvier)	Projet PADDII (UG, UCL, Cerva)	Après-midi d'études	LLN	RW
2005	Quelle gestion démocratique des OGM dans le cadre d'une politique de développement durable ? Journée de rencontre acteurs-chercheurs organisée « *Développement durable, sciences et société* » (8 février)	UCL-CITES- Chaire Tractebel-Environnement 2004	Journée acteurs-chercheurs	LLN	-
2006	Science et expertise, par Philippe Baret (17 février)	UCL, Dept de Droit Public	Séminaire court	LLN	-
2005	*L'expertise et la décision publique face aux transformations de l'espace public de la science, par Pierre-Benoit Joly (16 mars)*	UCL-CITES-Chaire Tractebel	Conférence scientifique	LLN	-
2005	*Agricultural ethics in a changing world,* by Martin Chrispeels (6 avril)	UCL-BDIV	Conférence scientifique	LLN	International
2005	*Réunion comité d'encadrement du projet SPF (23 juin)*	SPF Santé publique	Réunion comité d'accompagnement	Bruxelles	-
2005	*Designs on Nature : Science, Democracy and Public value* (13 september)	Demos	Journée-conférence	London	International
2005	*Lutte intégrée ou biologique en arboriculture fruitière (14 décembre)*	Région Wallonne – DG Agriculture	Après-midi d'études	Namur	RW
2005	*Pesticides, agriculture et environnement. Réduire l'utilisation des pesticides et limiter leurs impacts environnementaux. Expertise scientifique collective (15 décembre)*	INRA-Cemagref	Colloque de restitution de l'expertise collective	Paris	France
2006	*The future of food and farming, by Vandana Shiva (6 mars)*	UCL-CENV	Séminaire scientifique	LLN	International
2006	Les OGM peuvent-ils être utiles ? (13 mars)	PS-IEV	Colloque public	Bruxelles	RW, B et

					International
2006	PhD Student Day (29 mars)	UCL-EDIV	Colloque scientifique	LLN	-
2006	Governing technology for development – From Theory to Practice and back again (31 mars-1er avril)	Open University-IKD and DPP	Workshop scientifique	London	International
2006	Le principe de précaution peut-il représenter davantage qu'un cri de ralliement environnementaliste ? (2 mai)	UCL-ETES-MICH	Séminaire scientifique	LLN	International
2006	Forum Agriculture Durable (18 mai)	Politique Scientifique (Cluster Agriculture durable)	Journée acteurs-chercheurs	Bruxelles	Bel
2006	58th International Symposium on Crop Protection (23 mai)	UG	Colloque scientifique	Gand	UE
2006	Biotechnologies : Défis économiques et visions de la société (7 juin)	Association Belge d'Economie Rurale (ABER)	Journée d'études	Bruxelles	B-UE-Int

VIII) Grille de critères pour une évaluation systémique de la pertinence des innovations scientifiques (Chapitre 9)

GROUPS & SUB-GROUPS	CRITERIA	Additional information
1. ENVIRONMENTAL		
Genetic pollution	Risk on biodiversity due to gene flow ?	Impact due to (1) spread of the transgenic plants in the environment or (2) to transfer of the inserted genetic material to other organisms (weeds, bacteria,..)
Biodiversity	Risk on biodiversity due to direct ecological effects ?	(1) impacts on non-target plants and animals (toxicity, lack of food, …) (2) on beneficial insects ; due to (a) associated agricultural practices (b) new functions by the transgenic plants (Ex : Bt toxin)
Agrobiodiversity	Impact on diversity of crops and of crop varieties ?	Impact (reduction/increase) in the diversity of varieties/cultivars used for this crop
Chemical use	Impact on reduction of existing chemical use ?	
	Impact on relative toxicity of pesticides, fungicides and herbicides used ?	The impact on environment (water, air, soil, wildlife) include direct and secondary effects : (1) Effects of broad-spectrum herbicides, use of specific herbicides for resistant weeds/volunteers (2) Non-target effects of insect resistance (toxic effects) (3) Fate and consequences of insecticidal toxins in soil
Landscapes	Impact on diversity and quality of land use ?	The impacts can be due to a change in land use as a consequence of : (1) Crop rotations schedule altered (2) Crops in new areas (where not planted before) (3) Substitution between products allowing culture of one major crop rather than 3-4 other types (Ex : Utilisation of GM multi-purpose plants : colza producing olive oil) (4) Change in land cover over the year (5) acceleration of the trend to monoculture
Energy use	Impact on energy use of associated practices ?	Via use of fossil fuels, chemical intrants, etc.
Unexpected effects	Unexpected effects on environment ?	Ex : Phenotypic and genetic instability
2.AGRICULTURAL (TECHNIQUE)		
Efficiency to meet target / to solve problem	Is it preventive or curative ?	
Coexistence of cultures	Impact on the possibility of coexistence of different types of agriculture ?	Does the practice poses a risk of contamination of conventional and organic crops and seed systems (via gene flow, …), on the short and long run ?

Weed and pest control	Impact on availability of current pest management methods ? Is the innovation/strategy itself sustainable on the long run ?	Is there a risk of reduced efficiency of current pests, disease and weed control methods ? (Ex : some people suggest there is a risk of resistance evolution such as the development of weeds/insects/virus populations resistant to herbicide/Bt toxins) (Ex : superweeds, volunteers, ..)
Agricultural practices	Impact on current agricultural practices ? Possibility of combination with other practices and consequent efficiency increase ?	Via (1) Impact on difficulty/easiness to practice various types of crop rotations ? (The use of certain GM crops, such as the herbicide-tolerant crops, are not best compatible with all crop rotations schemes) (2) Impact on the flexibility of planting/protection treatments periods ?
3. SOCIO-ECONOMIC		
a) FARMERS		
Freedom to adopt or not	Impact on freedom of farmers to choose ?	Two reasons might reduce the freedom to adopt or not : (1) technical impossibility of coexistence of GM and non-GM crops because of progressive contamination of conventional and organic crops and seed systems (via gene flow, …) (2) economic difficulties for current non-adopters making it impossible not to adopt in the long-term (late or non-adopters tend to suffer financially, forced into the technological treadmill, except if they find niche markets)
Income	Impact on farmer income ?	Via an (1) increase/decrease of inputs (chemicals and seeds), labour and investments (2) improved yields without price reduction (3) price changes
Quality of work	Impact on quality of work ?	Ex : flexibility of work organization, dangerous use of toxic pesticides, administrative duties
Agricultural practices	Impact on agricultural practices ?	Ex : via a change in persistence or invasiveness of the crop ; weediness of crops (volunteers)
Adaptability	Ability to be adapted by farmers in their specific local/regional context ?	
Autonomy	Impact on farmer's autonomy (seeds and crops)?	Does the transgenic plants and associated commercial practices inhibits re-use, sharing and storing by farmers (1) by patent protection, intellectual property rights, liability contracts (2) by use of GURTS (gene use restriction technologies)
	Impact on farmer's autonomy (ability to buy inputs and sell outputs)?	Via an impact (+ or -) on the trend toward contracts integration
	Impact on farmer's autonomy (access to information and advice)?	Via an increase of power of private companies and/or a decline of public agricultural extension service

b) AGRO-FOOD CHAIN		
Agro-industialisation	Impact on the socio-economic structure of the agro-food chain ?	Ex : some innovation may allow greater opportunities for agro-industrialization such as via (1) vertical integration/concentration at different stages of food chains (Ex : GM plant linked with use of herbicide favours concentration between seed and chemical firms) (2) increasing substitution opportunities between products (3) by increasing production of major crops (commodities) for export instead of local foods in southern countries
Profitability	Impact on profitability in the food chain ?	Via an impact on (1) costs of inputs, labour, processing, controls (2) value added
Competitiveness	Impact on competitiveness of national agriculture (exports and imports) and agro-industry ?	Via new or lost markets
Breeding	Impact on classical breeding programmes and firms ?	
Stability	Impact on stability of food chain ?	Does the introduction of the innovation increase/decrease/has no impact on the food chain stability to food chain crisis
c) CONSUMERS		
Food safety	Impact on food safety ?	Risk of allergenic and immune system reaction to new substances ; antibiotic resistance marker genes
Health	Impact on general health ?	via pesticides residues, …
Nutrition	Impact on nutrition ?	via nutritious contents of foods
Affordability	Impact on retail price ?	
Transparency	Impact on transparency of consumer information ?	
Choice	Impact on freedom of consumers to choose ?	Freedom of choice is expected to be ensured by traceability and labelling schemes but 'relative' freedom of choice includes accessibility (are the different products sold everywhere and at an affordable price) ?
Trust	Impact on trust in food chain and broader agriculture ?	Does the introduction of the innovation increase/decrease/has no impact on consumer trust ?
4. SOCIO-POLITICAL (MACRO)		
Food security	Impact on general food security ?	Contribute to improve/decrease current and future general level of food security ?
General employment	Impact on employment in agriculture ?	Contribute to accelerate or decelerate the general decrease of employment in agriculture (# of farms and # of farmers) ?
	Impact on employment in agro-food chain ?	

	Impact on employment in research and development ?	
Farm and rural communities	Impact on farm and rural communities ?	Impact on decline of number farms, farm employment, etc…
Distribution of revenues	Impact on distribution of benefits of the technology ?	Via impact on (1) Distribution of benefits between biotech company, farmers, consumers, externalities (2) fair sharing of benefits of use of original genetic resources ?
Cultural	Impact on cultural identities of affected stakeholders ?	Agrobiodiversirty, traditions,…
Institutions	Impact on concentration of economic power in the agro-food sector?	Ex : tendencies to monopolies
	Impact on trust in public institutions ?	Institutional conflicts, ability of democratic practices to operate
	Impact on public budget used in regulatory framework ?	Via necessity to regulate agriculture if the innovation is allowed(coexistence; labelling, traceability, …) ? Need of public policies/investments to promote adoption ?
	Impact on need for traceability and complexity in system ?	Via the need for eventual control procedures.
Public policies and goals	What is the innovation's potential 1) to fulfill public goals concerned with agriculture and environment 2) to fulfil general public goals (competitiveness, employment,…)	
	Need for a shift of public policies	(in order to remove current obstacles to the development of the innovation, for example)?
Research	Impact on research orientations ?	Via (1) impact on independence of research institutions (2) new forms of public-private partnerships (2) use of research funds & skills (investment in GM research may undermine research on alternative options (='opportunity costs' : cost of not investigating other options)
Necessity ?	Is the innovation necessary compared to status-quo?	What is the problem at stake ? Does the innovation meet a social demand ?
Ethics	Is the innovation in accordance with our ethical concerns related to agriculture, food and society	Man's relation with nature : (1) in-principle objection (2) frontiers to transformation of living organisms (no cross of barriers of species : transgene from (un)related species)
5. UNCERTAINTY & IGNORANCE		
Effects not foreseen	Risks, Positive and negative effects not foreseen	
Scientific knowledge of the crop and its biology	Is the scientific basis for this innovation sufficient to allow its commercialization ?	

6. LONG-TERM, CUMULATIVE EFFECTS		
ENVIRONMENT	Impact on broad environmental change due to agricultural production ?	
SUSTAINABILITY & AGRICULTURE	Does the innovation/strategy induce a move towards a truly sustainable agriculture (Long-term, cumulative impacts)?	Does the strategy induce a move towards sustainable pest management ? Ex : (1) Risk of new forms of pathogens to control (recombination of viruses and bacteria to produce new pathogens)? (2) Diminution of agroecosystem complexity (inhibit use of certain rotations and polycultures)
	Does the strategy reinforces current model of agriculture and delays a greater reconversion of agricultural systems towards sustainability (agro-environmental dimensions and socio-economical)?	
AGRO-FOOD CHAIN	Does the innovation/strategy induce a move towards a truly sustainable agro-food chain/food consumption ?	Long-term, cumulative impacts (broader socio-economical change due to agriculture)
SOCIETY	Long-term change on development ?	Is it part of a (un)desirable trend ?
	Impact on the eventual irreversibility of our socio-economic development ?	increase / decrease / no effect on irreversibility
7. VARIED		
Side effects	Do the advantages of innovation/strategy outweight drawbacks/side-effects ?	
Other advantages	Does the innovation/strategy has positive effects on other problems than the original ?	new opportunities ?
Feasability of the innovation/strategy	Does the innovation/strategy needs great changes in the system (agricultural practices, investments, agro-food chain, …) ?	
8. FORGOTTEN CRITERIA	To be added by the users after first implementation	

IX) Why are 'ecological' disease-resistant wheat cultivars slow to develop commercially? A Belgian agricultural 'lock-in' case study

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Abstract

The use of disease-resistant cultivars allows a significant reduction of fungicides use in low-input crop systems. However, some major wheat cultivars used in Europe remain sensitive to the more frequent diseases and require important fungicide protection. This paper aims at understanding the barriers to the use of disease-resistant wheat cultivars in Wallonia (Belgium). Research on cultivar adoption has been an important research subject in the past, but few analyses have been done in Europe in the past decades. Meanwhile, cereal prices have changed, affecting wheat profitability. The attention given to the reasons explaining the weak or strong use of disease-resistant cultivars by farmers is rare. We led a systems approach combining a survey among stakeholders of the food chain and a systematic analysis of the publications of extension services. We identified twelve barriers, technical as well as socio-economic, which are located at different levels of the food chain: producers, input suppliers, research and extension, public rules and regulations. Similarities between the situations in Wallonia and in France are discussed. These barriers explain why current wheat cropping systems are maintained in a "pesticide lock-in" situation, an economic concept that could be more frequently used to study agricultural innovations. Considering these immaterial barriers to existing important innovations is a first step towards more comprehensive policies to promote sustainable agriculture. Leverages for a broader use of resistant cultivars are proposed.

Keywords: technology adoption; agricultural innovations; integrated crop protection; pesticide lock-in

Introduction

Disease-resistant cultivars have been bred throughout the world for a long time and are numerous among the range of commercially available wheat cultivars. Their advantages for producers are first a direct economic benefit (the reduced costs of fungicides and fuel due to a reduced need for fungicides applications) and secondly an indirect social amenity (reduced time and hassle of controlling crop health situation and of spraying). These two benefits are of greater importance when cereal prices are down (low prices make fungicide applications less profitable) and, to a lesser extent, for farms of expanding size with an unchanged workforce. These are two of the main current trends of cereal production in Europe. Wheat prices as calculated for Belgium were as high as 226 €/T in 1983 (Conseil Supérieur Wallon de l'Agriculture, 2002) but had constantly decreased, dropping below 100 €/T in 2004-05 when this research was conducted.

While the main benefits of disease-resistant cultivars are for farmers, society as a whole has a lot to gain from them as they contribute to broader pesticide reduction, which is recognized as a significant and worthwhile public objective because of the environmental and health problems linked to the use of pesticides, even if fungicides are supposedly less problematic than insecticides and herbicides (Wilson et al., 2001).

However, disease-resistant cultivars do not systematically become best-seller cultivars. On the contrary, many best-seller cultivars prove to be weakly resistant to one or more important disease and rely completely on fungicide protection. Why do disease-resistant cultivars fail to reach the top? Is the yield lag between the hardiest disease-resistant cultivars and the highest-yielding cultivars the only explaining factor for this failure, as the analysis of the 'yield penalties' of disease resistance in plants may lead one to conclude (Brown, 2002)? Besides the fact that yield and resistance are not always negatively correlated, our survey points to several other factors that influence the situation. The aim of this study is to understand all factors impeding the use of best disease-resistant cultivars by farmers. Our analysis led us to depict the current cultivar use and crop protection situation in Wallonia as a typical example of an agricultural system in a pesticide 'lock-in' situation.

We tackled this objective with a case study focusing on one cereal, winter wheat, in one specific European region, the cereal-growing part of Wallonia (Belgium). Section 1 of this paper presents the systems approach we conducted and Section 2 gives a brief introduction to the wheat production systems and crop protection situation in Wallonia. Section 3 is the analysis of the twelve barriers to the use of existing disease-resistant cultivars. Section 4 compares our Belgian findings with the situation in neighbouring France before discussion and conclusion.

I. Method

Our qualitative and multidisciplinary approach falls within the scope of soft systems approaches (Checkland, 1981; Ison et al., 1997). It consisted of two different methodological steps.

Firstly, a survey among stakeholders in the cereal agricultural sector and food chain was conducted in Wallonia during the 2004-05 winter. It consisted of 25 in-depth semi-directed interviews. Technical advisers from public extension services, private firm officials and scientists were interviewed about two important diseases in Wallonia:

Fusarium head blight (Fusarium spp. and Michrodochium nivale) and Septoria leaf blight (Septoria spp).

Questions aimed at understanding the use of several integrated crop management strategies, yet this paper focuses solely on the use of disease-resistant cultivar. Semi-directed interviews were based on a series of questions common to all interviews, but allow for secondary, in-depth questions that depend from the answers of the interviewed person. Examples of questions raised in all interviews are: What are the current agricultural strategies available to stop or reduce these diseases? How far do farmers use them? Why do farmers not use disease-resistant cultivars? Is the situation of disease-resistant cultivars different than a few years before? Why?

Specific questions were: What are you priorities for breeding programs (to breeders and seed companies)? What kind of research projects have been lead in the past, and are being led on disease control (to scientists)?

Secondly, the contents of the “Livre Blanc sur les céréales” (White Paper on Cereals), a bi-annual handbook published by public research institutions and extension services, was analysed for the period 2000-2005 (FUSAG and CRA, 2005). The White Paper is the main written source of independent technical advice for wheat producers in Wallonia. The Gembloux Agricultural University (FUSAG) and the Wallonia Agricultural Research Centre (CRA-W), both located in Gembloux, run this publication. The methodological details concerning the quantitative and qualitative analysis of the Livre Blanc are given in Section III.C (TABLE 2), where results for these analyses are shown.

A desktop research for grey literature published in the cereal sector initiated this systems approach and a literature review covering the diversity of involved domains completed it.

The combination of these different sources allowed us to rely on results from existing experimental research as well as on human experience accumulated by a diversity of professional stakeholders about how cereal production functioned. It enabled us to take into account qualitative as well as quantitative aspects, to cross and verify results obtained, for example analysing technical data in the light of the ‘real world’.

While the initial focus of the survey was put on only two diseases, they were taken as two among other frequent diseases in order to question stakeholders about their broader management of various diseases in wheat. Fungicide treatments are indeed done to protect plants from a wide array of fungal diseases, including rust and powdery mildew.

II. Wheat diseases, fungicide applications and cultivar choice

8000 farmers grow winter wheat on 130.000 hectares in Wallonia. Winter wheat is the main cereal in Wallonia, covering 70% of the cereal surface with a mean yield of 8.5 T/ha. Most of the winter wheat is grown under a conventional high-input cropping system with the exception of organic wheat and low-input systems under agri-environmental schemes for which a premium is given (reduced sowing density, use of maximum one fungicide application, no use of straw shorteners, greater attention on cultivar choice and fertilization) which represent each about 1% of the wheat surface. Wheat output is used for animal feeding, human consumption and the starch industry.

Most problematic diseases in conventional high-input wheat systems are Septoria leaf blight, brown and yellow rusts, powdery mildew and, more recently, Fusarium head blight (FHB). Septoria leaf blight has an important economic impact on wheat production (yield and quality). It is caused by S. nodorum and S. tritici and its impact became more pronounced in part due to increased genetic resistance of wheat to other foliar pathogens such as powdery mildew (Eyal, 1999). FHB is a cyclic disease, occurring once every 3 to 5 years (Champeil et al., 2004a). Once a limited disease for which no particular attention was paid in the region, FHB gradually became a major public concern with accumulating data on public health problems associated with fusariotoxins, especially deoxynivalenol (DON). FHB occurs in many regions of the world with yield losses reaching 50% under unfavourable conditions (Parry et al., 1995). Yield losses are limited in Wallonia but mycotoxin contaminations are a major concern during unfavourable years, such as in 2002 when over 35% of the analysed samples exceeded the EC recommended DON level (Chandelier et al., 2003a). Maximal DON levels vary depending upon the final use of grain: baby food, human food or animal feed.

Fungicide applications differ from one plot to another according to agro-meteorological conditions, pathogen epidemics, crop cultivar as well as farmer objectives and aversion to risk. Average quantities of active ingredients for wheat were reduced during the period 1991-2000: total quantity of crop protection products went from 4.7 to 3.2 kg/ha and fungicides quantities from 1.7 to 0.7 Kg/ha (Ministère des Classes Moyennes et de l'Agriculture, 2002). However, the cost of crop protection rose from 124 to 162 €/ha from the year 1994/95 to 2000/01 (Groupe de travail de la filière Céréales, 2003). Farmers do one to three fungicide applications a year (mostly one or two) and each application generally consists of mixtures of fungicides, mainly triazoles and strobilurins. Fungicide applications for both diseases are problematic. The apparition of Septoria populations resistant to strobilurins fungicides has been rapid and occurred on a European scale. In a three year period, the effectiveness of this new active ingredient has decreased so tremendously that it is advised to use it only in mixtures with other substances (Moreau, 2004). Worse, fungicide applications for FHB are poorly effective: applications must be done during the very short flowering period, when kernels are sensitive, which allows only a little flexibility from the farmers. The best active ingredients control disease incidence by only half (Chandelier et al., 2003). Fungicide applications can in certain cases even stimulate mycotoxin production, which led scientists to advise applications of fungicide mixtures (European Mycotoxin Awareness Network, 2005). In Wallonia, a general alert system based on visual observations in farmers' fields is run by extension services and informs cereal producers about pathogen development for various diseases and gives advice for pesticide applications.

In 2004, eighty cultivars were multiplied in Belgium, from which 44 cultivars were registered on the Belgian national cultivar catalogue (Ministère de l'Agriculture, 2005) while the other were available through the European cultivar catalogue. Public extension services in Wallonia conducted field tests for a great number of these cultivars: in 2004, 52 cultivars were assessed in the White Paper on Cereals for basic characteristics such as yield or phytosanitary contribution to yield (rate of « loss » of untreated plot against treated plot, in percentage of kg/ha).

Extension services present a further analyse of 24 cultivars presented as "main" or "recommended" cultivars (only 11 of which are registered on the Belgian catalogue). Additional information is given to farmers for these cultivars, such as cultivar susceptibility to diseases. Scores for cultivar resistance to diseases are a synthesis of data from experimental fields and visual observations in farmer's fields. Four levels of resistance are determined (4 is the highest resistance) for each of the four frequent diseases (Septoria leaf blight, brown and yellow rust and Fusarium head blight). In this paper, we define level 1 and 2 as "poor " and "low" resistance while we speak of resistant cultivars for level 3 and 4. In 2004, twelve out of the 24 main cultivars had a poor or low resistance to Septoria leaf blight and five to Fusarium head blight. Only six were multi-resistant (level 3 or 4 to each of the four common diseases: Septoria leaf blight and FHB, brown rust and yellow rust).

If cultivar use can be assessed by official seed multiplication areas, these multi-resistant cultivars accounted for only 26 to 31% of total wheat surfaces in Belgium between 2003 and 2005. Multi-resistance, here, does not take into account cultivar susceptibility to powdery mildew and other diseases that are not systematically studied by extension services for this list of cultivar. Real estimates, optimally based on surveys among farmers, thus are probably lower.

III. Barriers to the use of existing disease-resistant cultivars

We looked at the different elements that impede the use of disease-resistant cultivars from becoming the mainstream and systematic cultivar choice by farmers in Wallonia. Our systems approach uncovered twelve barriers (impediments) to a broader use of multi-resistant wheat cultivars (Table 1). These barriers are technical or socio-economic, obvious and non-obvious. They are grouped according to the agri-food chain level they influence: farmers, the market, public extension services and research, public regulations and past agricultural policies.

Table 1: Barriers to a systematic use of resistant cultivars. There are twelve barriers to a wider development and use of multi-resistant wheat cultivars

Farmers
1) Direct cultivar choice criteria of farmers: disease resistance comes only after gross yield, resistance to lodging or commercial quality
2) Incomplete resistance of resistant cultivars and the unpredictability of epidemic development
3) Limited number of cultivars resistant to all frequent diseases
Market
4) Contradictory objectives of input supplier: crop protection and seed departments have contradictory objectives. The imbalance between both departments plays at the disadvantage of resistant cultivars
5) Influence of salesmen of input suppliers on farmer's practices
6) Breeding history and breeding objectives of seed companies
Public extension services and research
7) Omnipresence of gross yield and absence of economic optimum estimates
8) Concentration on one cultural system at the expense of alternative systems
9) Perception of- and information given on resistant cultivars
Public regulations
10) Cultivar registration norms
11) More important challenges: food safety, traceability, etc.
Past agricultural policies
12) Payments based on output influenced cultivar choice towards highest-yielding cultivars

A. Barriers at the farmers' level

1. *Criteria for cultivar choice*

The first barrier is the direct criteria for cultivar choice by farmers. According to extension services officers, resistance to diseases comes only after four main criteria such as gross yield, resistance to lodging (yield security), earliness, and commercial quality, such as protein content. A survey among a hundred farmers in the intensive cereal-growing region of Wallonia confirmed that the main criteria were yield (main criteria for 64% of farmers) and commercial value (22%) while resistance to diseases ranked only third (14%) (Marot et al., 2005). Extension services officers also reported that the prestige of maximal gross yield remains predominant in farmer-to-farmer contacts and a glimpse at the agricultural press can confirm that it is indeed a powerful criteria in the whole agricultural sector. Farmers thus generally consider resistant cultivars only if they rank best for yield, which dismisses a number of them.

2. *Incomplete resistance of resistant cultivars*

The second barrier is the incomplete resistance of resistant cultivars and the unpredictability of annual prevalence of the various diseases. Few cultivars are completely resistant to diseases and degrees of resistance may evolve from year to year due to agro-meteorological conditions and pathogen evolution. As agro-meteorological conditions differ from one year to another and greatly influence diseases damage, the risk of extensive disease damage is unpredictable and exists for all non-totally resistant cultivars, as complete resistance is rare. As a consequence, the actual benefit of choosing resistant cultivars can only be fully assessed at the end of the season, which is relevant for a scientist but not so much for a farmer.

3. *Limited number of cultivars resistant to all frequent diseases*

The third barrier is the limited number of cultivars that are resistant to all frequent diseases. Few cultivars have a high level of resistance against each of the four most common diseases in the region (FHB, Septoria leaf blight, brown and yellow rust). Most cultivars resistant for one disease have at least a weakness for one or two of the other diseases, which makes choice of resistant cultivars harder as all diseases are expected to occur. In 2004, only five cultivars had a “good resistance” (level 4 out of four levels) to the four diseases out of the list of 24 main cultivars. Fungicide applications are thus needed in a number of conditions even when using resistant cultivars.

B. Barriers from the market system

Private stakeholders influence crop protection practices in three ways: (a) an internal bias within input suppliers in favour of fungicide sales compared to seed sales, (b) a bias of supplier salesmen in favour of fungicide applications and (c) a weak priority given to breeding for disease resistance in seed companies.

1. *Internal bias within input suppliers in favour of fungicide sales compared to seed sales*

Input suppliers have a preponderant role in the cereal sector: these firms sell crop protection products, fertilizers, seeds, advice and agricultural machinery to farmers and also collect their cereal output. In Wallonia, two large organizations share two thirds of this market (one private firm and one farmer cooperative). In each of these two input suppliers, the seed department accounts for a very small share of the sales (6-7%) compared to the more profitable departments of crop protection products and fertilizers. According to a seed department head, this internal imbalance greatly influences the firm’s activities up to the choice of cultivars on which the organization takes licence.

The contradiction lies in the fact that a seed department should promote best resistant cultivars while this is not a priority for crop protection and fertilizer departments, which focus on cultivars with the highest yield. Suppliers primarily make money with fungicides and not with seeds. The fact that seeds and crop protection products are sold by the same distribution networks thus has a key influence on the weak development of resistant cultivars.

2. *Bias of input suppliers salesmen in favour of fungicide applications*

The second barrier also lies on the side of input suppliers. Local salesmen of input suppliers have the greatest influence on farmers, especially since a network of regional public extension officers has been closed. They are the only external technical advisers that have direct and regular contact with every farmer. Salesmen advise farmers on cultivar choice as well as on crop protection products and fertilizer choice. As they are partly paid according to sales, it induces a second bias in favour of high-input systems. The highest-yielding cultivars that perform best under high-input conditions are thus promoted even if they may be poorly resistant to diseases. Fungicide applications are promoted, even in a number of situations where it is unnecessary. A second fungicide treatment is indeed often promoted as farmers think of fungicides as forms of insurance, especially risk-averse farmers, even if this second treatment is not always needed and profitable. This influence is mentioned by public extension officers in interviews as well as in their articles in their annual handbook (FUSAG and CRA-W, 2005).

3. *Weak priority given to breeding for disease resistance in seed companies*

The third barrier comes from breeding companies. The real importance of breeding for resistance in private breeding programs is a controversy. While many mention it is a priority in all breeding programs (Eyal, 1999), some private breeders recognize that resistance is not as important an objective in their programs as in public breeding programs. One private Belgian breeder acknowledged being satisfied with the results of their four-year greater attention on disease resistance but having now return to a greater focus on yield and grain quality than disease resistance. Actually, real progress in resistance improvement takes long periods: public breeding centres have fewer constraints to engage in this objective than private breeders, which have short-term profitability constraints, such as ‘put at least one cultivar on the market a year’ to remain competitive. In the nineties, the only public breeding centre in Wallonia decided to give a priority to hardy cultivars (disease-resistant wheat and spelt cultivars that perform well under low-input conditions).

This does not mean that modern cultivars have weaker resistance levels than old cultivars but that there has been an under-investment in this breeding objective. During the three last decades, the existence of fungicides and the focus on high-input systems has indeed led to a greater focus on yield than on resistance. As a consequence, breeding for resistance was not very profitable. Breeding efforts for resistance to diseases have thus been insufficient compared to what breeding could offer now, in terms of commercial cultivars, if their main objective has been to produce hardy cultivars. Besides, breeding for resistance programs have focused on vertical resistance rather than horizontal, polygenic, resistance. This strategy is not sustainable as the example of the breakdown of Yr17 resistance to yellow rust showed (Bayles et al., 2000).

C. Barriers from extension services & analysis of the ‘Livre Blanc’ contents

Public extension services influence cultivar choice and agricultural practices. In Wallonia, public extension on wheat production is run by the Centre de Recherche Agronomique de Wallonie (CRA-W, Wallonia Agricultural Research Centre) with the contributions of the Facultés Universitaires des Sciences Agronomiques de Gembloux (FUSAG, Gembloux Agricultural University) and the bio-engineering faculty from the Université de Louvain (UCL). To study the role of public extension services, we relied both on interviews of stakeholders and on the analysis of the contents of the Livre Blanc ("White Paper on Cereals by Gembloux") published between 2000 and 2005. This bi-annual handbook is composed of regular papers updating advice on main themes and occasional shorter papers on current issues. Its formal name is "Fumure et Protection Phytosanitaire des Céréales" but it is known as the "Livre Blanc". The main intent of the handbook is to popularize results from the latest research and give the best advice to farmers accordingly.

The 125 published papers were first classified following their main subjects, such as 'fertilization', 'wheat quality', 'weeds', etc. All papers related directly or indirectly to diseases and crop protection were selected: regular large papers on 'wheat crop protection' and on 'fungicides' (up to 60 pages-long) as well as occasional papers on 'head blight and mycotoxins', 'wheat cultivars and diseases', 'organic wheat' and 'agri-environmental schemes'. This lead to a selection of 31 selected papers, which accounted for 43% of the total volume of the publications during the period (chosen indicator of importance is number of pages of papers as papers differ widely in size). These papers were then analysed on the type of information and of research results they contained. The tables presenting research results were retained as a proxy of the information given to farmers. Advice was indeed consistent with the type and contents of tables presented in papers.

The selected papers contained 205 tables presenting results from experimental research carried out in Gembloux and other research sites or on-farm experiments in Wallonia during 2000-2005.

The great majority of experimental research concerned the influence of one variable - such as sowing date or cultivar choice- on gross yield (46.3%), the phytosanitary contribution to yield (27.3%), cultivar disease susceptibility estimates (10.2%) or the disease development in a crop (9.8%) (Table 2)

Table 2: Analysis of the experimental research in the « Livre Blanc ». Results from agricultural experimentations conducted between 2000 and 2005 were presented in 205 tables of results, which are classified according to the type of results and the type of field tests.

	Number (n=205)	Percentage (%)
Type of result		
Influence of one variable on gross yield (kg/ha)	95	46,3
Phytosanitary contribution to yield (kg/ha)	56	27,3
Cultivar disease susceptibility estimates (scale of 1 to 4)	21	10,2
Disease development in a crop (% affected surface)	20	9,8
Difference of revenue between various crop systems (expressed in kg/ha)	16	7,8
Mycotoxins estimates (DON or mg/kg)	7	3,4
Type of field tests		
Long term experimentation (above 3 years)	37	18,0
Comparison between various crop systems	35	17,1
Comparison include low-input systems under agri-environ. schemes	20	9,8
Tests on organic fields	2	1,0

The three important elements that interfered negatively with a strong use of resistant cultivars by farmers: (a) the omnipresence of gross yield calculation and the absence of economic optimum estimates (b) the concentration of applied research on one cropping system and (c) the perception of resistant cultivars by extension services officers. Results were consistent with interviews and observations of advice given by extension services in public presentations to farmers.

1. *Omnipresence of gross yield calculation and absence of economic optimum estimates*

The quest for the highest gross yield is not only a basic objective of farmers. Public extension as analysed by the content of the White Paper on Cereals relies systematically on gross yield and very weakly on economic optimum. While a small half of the results from experimental cereal research focused on gross yield (46.3%), only a minor part (7.8%) introduced a more comprehensive economic analysis by including the costs of inputs for cropping systems making a moderate or intensive use of inputs (fertilizers, fungicides). In the five-year period, only one paper introduced a full economic analysis in which units were euros and not kg/ha (other results 'translate' costs of inputs such as crop protection products or spraying applications and fuel in 'equivalents kg/ha'). The rare economic analyses were not absolutely complete, as acknowledged by one author, as it took no account of the economic value of straw although cultivars differ in straw height, an element that may become important when grain prices are low.

What is most surprising is that the results of this uncommon research work on economic optimum in cereal production gave original and interesting results. Conclusions were convergent: the quest for the highest gross yield is no longer the best strategy to maximize net gross margin when wheat prices are low (Soete et al., 2003; Buyze et al., 2003; Dekeyser et al., 2003). Instead, a choice of disease-resistant cultivars in low-input systems could reach economic optimum when agri-environmental premiums of Common Agricultural Policy (CAP) second pillar were taken into account. With current wheat prices (below 100 euros/T), the cropping system giving the highest margin differs from one cultivar to the other. For some cultivars, the high-input system was still the best system but input intensification is not anymore a systematic winning strategy in all cases.

Input suppliers minimize the importance of such studies: they do not publish their own economic optimum studies. This is understandable as they rely on input sales and have no interest to sell a resistant cultivar instead of a susceptible cultivar. As one manager put it clearly in an interview: "Entre nous, calculation of gross yield suits the whole business: the agricultural press, the phytosanitary companies, etc. It goes towards greater consumption. Everyone has an interest in it ". Yet, given the fact that cereal prices have been down for years, one could expect that public extension services would act otherwise and that the studies on the economic optimum of high- and low-input systems would become systematic in the public-published biannual extension handbook (which aims at giving the best advice for farmers) that scientists would look for further confirmation or affirmation of results. Instead, this type of result has not been published since 2003. Positive results of low-input systems were nevertheless confirmed with additional yet unpublished results (Dekeyser et al., 2005). A few resistant cultivars were even most profitable in low-input systems in the absence of the agri-environmental scheme.

Results from our survey were consistent with the above findings. During interviews, only advocates of resistant cultivars raised the issue of economic optimum. Public extension officials either opposed such calculations or discussed the many difficulties to calculate it such as the costs to implement this new type of calculation, the fact that the results from such calculations were less visible and understandable than gross yield, the fact that the calculation was more complex as more variables have to be taken into account or the difficulties to adopt a standard calculation as some farmers take into account the costs of labour or oil and others do not. A few also showed indifference to economic optimum estimates which seemed to them an insignificant estimate for farmers since their variable expenses are low compared to their fixed expenses such as farm rentals and loan reimbursements. Whether farmers calculate their economic optimum themselves or not is an open question. Surveys have not been made in the region on farmers' trains of thought. However, most scientists and public extension officers argue that farmers or even agri-managers do not calculate economic optimum. In any case, it seems rather unconceivable that one can analyse results from twenty to seventy cultivars and compare results for three different cropping systems (low, moderate and high-input) without appropriate information and tools.

2. *Perception of- and information given on resistant cultivars.*

Following prominent public extension officers, cultivar susceptibility to a disease is "the probability to have to spray at one given moment". A resistant cultivar "raises the probability of not having to apply two fungicides (which is largely the case) and allows a greater tolerance in the moment of application" (which is of great value for farmers that may also be busy with livestock management or other activities) "without excluding an intervention" (Couvreur and Herman, 2002). Public extension officers thus promote their own particular perception of resistant cultivars: while they advise choosing cultivars resistant to the most systematic diseases (Septoria leaf blight and brown rust), they fail to insist on the economic interest of resistant cultivars in a number of cropping systems. This may contribute to the fact that farmers consider resistant cultivars as a tool complementary to fungicide applications.

3. *Concentration of applied research on one cropping system*

The third element that we analyse as a barrier to a systematic use of the best resistant cultivars is the concentration of experimental research on one cropping system at the expense of alternative systems.

In the “White Paper on Cereals”, research on agri-environmental schemes was published in six papers between 2000 and 2003 and research on organic wheat only once in 2001 and in 2002 (two one-table two-page papers). When considering the entire period, research presented to farmers only took into account agri-environmental schemes in 10.6% of tables and organic wheat in 1.1%. This research was exclusively published in specialized papers on agri-environmental schemes or organic wheat. Regular papers on general wheat production reproduced research on agri-environmental schemes only once over the entire period and never compared conventional and organic wheat production systems. Moreover, the occasional papers focusing on agri-environmental schemes monopolized the majority of research on economic optimum (12 out of 14 research tables) as well as comparative results between systems of different input levels (21 out of 32 research tables). Large-scale comparisons between different cropping systems, including organic systems, are indeed rare (Champeil et al., 2004b).

Experimental conditions of cultivar field tests also reflect this concentration on one particular cropping system. Experimental fields are sprayed twice with fungicides to fully protect the plant from disease damage, as the main objective is the assessment of the gross yield potential of cultivars. Other considerations also play a part, such as the desire of farmers that host cultivar field tests to show “nice” fields. The way field tests are conducted is particularly important because results from cultivar tests by public extension services are relatively important in the cereal sector. Results from the main network of cultivar tests influence farmer choices but also seed companies’ strategic decisions such as seed multiplication surface areas. The choice to double-spray experimental tests (instead of systematically comparing results with one and two applications) may thus induce farmers to adopt the same strategy even if it is not the optimal strategy from an economic point of view.

Besides, we were able to observe in our survey that scientists were interested in qualtitative, multidisciplinary, non-experimental research such as the one they were interested for. However, they did not lead such projects themselves and had a poor knowledge of results from such research. Interviewed stakeholders and scientists could hardly cite any socio-economic research works or surveys on farmer strategies, decision modes or use of external information made in the region. One prominent scientists cited only two: one in 2004 and the previous one in 1985 (Marot et al., 2005; Duveiller et al., 1985). Studies on the development, advantages and drawbacks of agri-environmental schemes such as low-input wheat systems drew only a little interest from the agricultural research community. Data on market share of each commercial cultivar, on cultivar genealogy and heterogeneity, on fungicide application strategies and crop rotation schemes made by farmers was unavailable although all would be necessary to assess how improvements in integrated crop protection could be done. This low commitment to social sciences and non-experimental research in general results in a limited reflexiveness capacity inside the agri-food chain.

When combined, the three elements listed above give a weak signal to farmers that resistant cultivars and alternative cropping systems could be a profitable system. Publications by extension services, and agricultural press in general, matter. As communication theorist Cohen observed in what became a widely accepted fact in communication, “the press is significantly more than a purveyor of information and opinion. It may not be successful much of the time in telling people what to think, but it is stunningly successful in telling its readers what to think about” (Cohen, 1963). A systematic calculation of gross yield instead of economic optimum, a focus on high-input systems and a disregard for low-input systems contributes to influence cultivar choice strategies.

D. Barriers from public regulations

Public regulations also greatly influence agricultural practices. We could identify public norms and regulations that had a direct or an indirect influence. The first directly concerns cultivar use and the second relates to the broader cereal production.

1. Cultivar registration norms

In Belgium, experimental tests for registration are historically conducted with fertilizer use matching farmers' practices but under no-fungicide conditions. These conditions are thought to positively influence acceptance of disease-resistant cultivars as they perform better than sensitive cultivars under these conditions. Indeed, new cultivars are assessed following a grid of criteria and receive a positive or negative grade for each criterion depending on whether its results are better or worse than the mean for that criterion. This grade is then multiplied by a weight according to importance of each criterion (1 for yield, 0.9 for resistance to lodging, 0.2-0.3 for resistance to each of the four diseases). Grades are finally summed up to give a final mark that will result in cultivar acceptance if it is positive. The impact on resistant cultivars is thus only moderate: cultivars can actually compensate for a high susceptibility to a disease with a high score for yield. Besides, the procedure may dismiss some hardy cultivars: resistant cultivars that perform well under low-input conditions may not outperform highest-yielding cultivars in highly fertilized conditions.

2. Prevailing challenges in the agri-food chain

Two important challenges, food security and food traceability, are conflicting issues with pesticide reduction efforts and promotion of integrated crop production. These socio-economic issues that are not directly related to crop protection worry all stakeholders a lot more than a reduction of fungicide use and this fact has to be linked with cultivar use. New constraints such as Integral Management of Food Chain Quality, monitoring of contaminants in the food chain or traceability schemes are indeed the number one problem of all stakeholders. European and Federal public regulations are being implemented or even anticipated at all levels. Our survey showed that this puts a heavy burden on all public and private organizations involving costs, human energy and time. In comparison, a recent Federal program of pesticide reduction was not even mentioned in any interview and prominent public stakeholders were not aware of it. Public extension services, civil servants in administration and scientists involved in applied cereal research have finite time, energy and resources that are used to face and manage these current most important priorities. Food safety and traceability are thus indirectly in the way of an increased attention of all stakeholders on the importance of cultivar disease resistance or broader pesticide reduction programs (FHB is an exception on this point as we will see).

E. Bias induced by past agricultural policies

A number of barriers relate to the importance of gross yield and the biases it induce on cultivar choice and cropping system choices by farmers. For some time, farmers have received agricultural subsidies based on their output level. As these payments were a major part of farmer revenue, this aspect of CAP is thus largely responsible for the bias towards the greatest yield achievable. It pushed farmers towards the quest for the highest yield, influenced breeding objectives but also estimating modes in extension services. Without this bias, farmers may have been more accustomed to economic optimum rather than gross yield.

IV. Comparison with the French situation

Wallonia, as a cereal-growing region, is rather small. However, France faces a comparable situation as far as resistant cultivars and low-input systems are concerned. Following official surveys among farmers, multi-resistant hardy cultivars represented less than 3% of French wheat surfaces in 1999 (INRA, 2001) and 16% in 2004 (Rolland et al., 2005). The French definition of hardy cultivars fits within the context of low-input systems: it includes productiveness and multiple disease resistance but allows susceptibility to one disease, such as FHB (Rolland, personal communication). Such cultivars were studied in France on a large network of field tests between 1999 and 2002 (Meynard et al., 2003) and further extended in 2003-2005 (Felix et al., 2005; Rolland et al., 2005). The latter program concluded that in 45 out of 66 locations, the combination "hardy cultivar – low-input system" gave the highest margin. Moreover, this combination had satisfying economic results with different scenarios of prices, showing its strength in different economic contexts.

Hardy wheat cultivars are often presented today as a success story of public agricultural research. However, the historical analysis of contemporary plant science research in France by Bonneuil and Thomas (2006) demonstrates that the development of hardy cultivars depended solely upon the strong will of a few scientists which went against the flow up to the late 90s, when wheat prices had fallen and agricultural professionals start to look differently at their results. Main barriers against disease-resistant cultivars are similar as those analysed for the Belgian situation. Impediments run from the strong political will within research institutions to invest in hybrid wheat and plant biotechnologies rather than in traditional plant breeding for hardy cultivars to the censorship by public technical institutes -which run main agricultural journals- on the publication of results from field test research and economic optimum analysis of hardy cultivars in low-input systems. The negative role of farmer cooperatives, which are input suppliers, and extension services has also been mentioned as a barrier to the development of hardy wheat cultivars (Meynard and Savini, 2005).

The role of private breeders in the development of hardy cultivars is controversial among scientists and stakeholders of the cereal sector. While a few breeders have been involved in the development of hardy cultivars for decades and have produced sufficient cultivars to fit all needs today, it is argued that the main farmer cooperatives and breeders (some of which are partly owned by agro-chemical companies) have long promoted cultivars best adapted to high-input systems. The cultivar registration norms have i.e. been a constant stake of negotiation and power between promoters of hardy cultivars and promoters of high-input systems (Bonneuil and Thomas, 2006). Within plant breeding, the transition of putting breeding efforts from vertical resistance to horizontal, polygenic resistance, is not started by all breeders yet it is a more sustainable strategy.

V. Discussion

Systems approaches are useful to understand technological, agronomical, socio-economical and organizational dimensions of complex problems. While it is here used to study technology adoption, its principles have also been used to identify why and when food systems fail to deliver safe products (Hennessy et al., 2003) or to discover impediments to the development and use of non-chemical alternative strategies to pesticides (Diamand, 2003). This case study is limited to a specific crop, a few diseases and a particular region yet we consider that our results have a broader significance as comparable situations in other countries were found.

Our analysis demonstrates that the current cultivar use and crop protection schemes in Wallonia gather many elements of a “lock-in” situation.

Lock-in and associated path dependence concepts have been suggested to explain the stability of socio-technical systems, particularly the sensitive dependence of competing technologies to initial conditions when increasing returns occur (David and Arthur, 1985; Arthur, 1989). Among several technologies that perform similar functions and compete for adoption by economic agents, one technology may become dominant, even though it may have an inferior long-run potential. This ‘path dependant’ process is self-reinforcing and may lead to a technological ‘lock-in’ situation in which the dominant technology excludes competing and possibly superior technologies (Liebowitz and Margolis, 1995).

The existence of path dependence and lock-in processes has been shown in the realm of agriculture, such as for pest control strategies, even though most of the path dependence literature focus on technological change in industry (Cowan and Gunby, 1996). The barriers we identified in this case study are comparable to the factors Cowan and Gunby analysed as impediments against a switch from one pest control strategy to another: uncertainty, coordination problems, technology immaturity, inflexibility, technology inertia and path-dependence.

Chemical pesticides gradually became the main pest control strategy during the twentieth century. Modern wheat cropping systems are now “locked-in” in a fungicide-dependency situation, even though the global situation (wheat prices, crop protection costs, cultivar characteristics, alternative crop protection strategies, available scientific knowledge) has changed, and questions the validity of past production cropping systems. Our findings are coherent with other analyses that do not use the lock-in concept but focus on the necessary conditions for adoption of farming-systems innovations by farmers (Pannell, 1999). The existence of barriers to disease resistant cultivars has also been analysed in other agri-food chains. In the case of apple trees, thirteen barriers explain the current failure of scab-resistant cultivars to become the main commercial cultivars despite the fact that these cultivars can save up to 70% of the necessary fungicide treatments (Vanloqueren and Baret, 2004a).While the apple sector is very different from the wheat sector, it has been shown that modifying the practices in the orchard consequently requested special efforts and conditions in the entire agri-food chain, which is also valid for the wheat sector (Collet and Mormont, 2003; Vanloqueren and Baret, 2004b).

An agricultural system can thus be locked-in in past solutions and get blocked from current optimal solutions. This situation is dependent upon past paths taken by farmers, extension services, agricultural policies and agricultural research systems. If the society as a whole considers this situation sub-optimal, scientists as well as public authorities have a role to play to contribute to the transition towards more sustainable systems.

The phasing out of input intensification in wheat cropping systems induces a need for both long-term and large-range experimental studies, a neglected research area within agronomy (Meynard et al., 2003; Meynard and Savini, 2005). It also requires multidisciplinary research. Teams composed of agronomists, economists and also sociologists may be best fitted to deal with such challenges. Agricultural science thus must meet sociology (Dunn, 1992) and socio-economics, especially on matters such as the study of choice, forecasting and adoption of technologies.

A general switch to a systematic use of multi-resistant cultivars in the context of integrated crop protection will take more than a gradual adaptation of farmer strategies to cereal prices, as the neoclassical economic theory assumes. Strong barriers play against a switch to low-input cropping systems and use of disease-resistant cultivars. The inertia within human structures that advise farmers and the influence of firms that have interests in the status quo situation are great.

Some obstacles to the use of resistant cultivars can be removed. Public authorities can decide to seize different opportunities to accelerate the use of resistant cultivars as a part of broader plans to improve agriculture competitiveness or as a means to accomplish further pesticide reduction programs.

Our focus on two very different diseases is interesting for that matter. The case of FHB and associated mycotoxins is illustrative of how public authorities can still have an impact on food chain activities even for globalized and free agricultural commodity markets. The outlook of a new binding European directive on mycotoxins led the whole cereal sector to anticipate it at all levels. Market stakeholders have introduced maximal levels of mycotoxins in wheat even in the absence of binding rules. A few specialized food chains have created a list of recommended cultivars while breeding programs, private and public, integrated new sources of resistance to FHB. Research institutions have launched specific task forces and research programmes such as risk forecast models or low-cost mycotoxins detection toolkits. These efforts are coordinated on the European scale for a chain-wide strategy (Scholten et al., 2002). Pesticide reduction efforts are on the contrary weakly coordinated in Wallonia. Other countries, such as Denmark, have obtained great success with long-term pesticide reduction efforts.

The first leverage on which public authorities may act upon are norms for cultivar registration. In a number of countries, minimal levels of cultivar resistance to FHB have been introduced as part of broader plans to control risks of contamination of food chains by mycotoxins (Ruckenbauer et al., 2004; Snijders, 2004). Minimal levels of resistance to each of the most frequent diseases would be a strong incentive for breeders to invest more resources in breeding for disease resistance. Likewise, the registration procedure might include an ex-post assessment after a two- or three-year period: cultivars that lost resistance in time due to pathogen adaptation could be removed from the market or charged extra costs for registration maintenance. Registration procedures should also be adapted to fit with low-input cropping systems by testing cultivars in such conditions (low fungicide and fertilizer use) in order to promote hardy cultivars. These institutional innovations would have to be adopted on a European scale to have a best impact.

Next, extension should be adapted to new socio-economic and societal trends. Public action must indeed induce a paradigm shift to overcome strongly enrooted socio-economic trends. Productivism (Walford, 2003), illustrated here by the prestige of maximum gross yield, must be replaced by objectives such as economic and environmental efficiency. Extension publications thus have to be remodelled as the single fact that they presently focus on yield, and not economic optimum, has great importance. As price conditions vary annually and cultivar turnover is high, research and extension should focus on answering a presently unasked question: “Is the systematic choice of the best multi-resistant cultivars –and of low-input systems- the most profitable choice for a farmer on a 3, 5 or 10 -year perspective?”. Cultivar choice software may become a great tool for better cultivar choice (Barbottin et al, 2006). Economic and environmental optimum estimates could be done for all cultivars in cropping systems with varying levels of inputs (fertilizers, fungicides and straw shorteners) and for different wheat price scenarios. More comprehensive information about the advantages of resistant cultivars could also be diffused. Given the high turnout in cultivar use, the fact that cultivars loose resistance over time -just as the best current cultivars are surpassed by future cultivars for yield-is not a problem if breeding produces new cultivars with improved resistance.

Conclusion

The failure of disease-resistant wheat cultivars to become a mainstream cultivar choice in wheat production is not intrinsic to poor technical characteristics such as lower yield or bread-making quality. Barriers impeding the development of resistant cultivars exist at all levels of the food chain, from farmers to input suppliers to CAP policies. Even extension services do not fully support the use of disease-resistant cultivars in low-input systems, despite their recent economic successes. It is shown that modern wheat systems are locked-in in dependence situation towards high inputs use (fertilizers, chemical pesticides and straw shorteners). The development of hardy multi-resistant cultivars and profitable low-input systems will request planned efforts, not only improved cultivars.

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