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1 **The micro-economic impacts of a ban on glyphosate and its replacement with mechanical weeding** 2 **in French vineyards.**

3
4 In France, viticulture is the production sector that uses the highest amount of glyphosate per
5 hectare. The prospect of banning this pesticide in France, and in Europe as a whole, has led us to
6 study the existence of alternatives to this herbicide, following article 50.2 of the European regulation
7 1107/2009, and to estimate the additional costs involved. Based on a national public database, we
8 synthesized the different weed control practices in viticulture and calculated their costs. Our results
9 showed that alternative methods to the use of glyphosate are more or less widespread depending on
10 the wine-producing area in France.

11 Inter-row non-chemical weed control is widespread and involves mechanical operations, with or
12 without the use of cover crops. The most difficult aspect concerns weed control between vine stocks
13 within the rows (intra-row), without applying herbicide. The size of the farms, the structure of the
14 vineyards and especially the distance between rows largely account for the differences in the
15 adoption rates of glyphosate-free practices in wine-producing areas. In total, the additional cost of
16 mechanical weeding compared to glyphosate chemical weeding is €250/ha on average, and varies
17 from €12 to €553/ha depending on the wine-producing area. The generalization of alternatives to
18 glyphosate-use under the European ban on glyphosate could have economic consequences on the
19 income of farmers, the magnitude of which depends on several factors, including the type of
20 vineyard, availability of labour and equipment on each farm, as well as marketing channels.

21 ***Keywords: glyphosate; economic impact; mechanical weeding; labour costs; machinery costs.***

22

23 **Introduction**

24 Reducing the use of pesticides is one of the objectives shared by many European countries in
25 accordance with European Directive 2009/128. This reduction is the subject of public policies
26 established at a European and/or Member State (MS) level that involve incentives for a decrease in
27 pesticide use, such as taxes or subsidies, as well as binding regulatory procedures regarding their

28 marketing, or even their ban. Numerous policies have been implemented, but most of them have
29 not been successful (Finger et al., 2017; Hillocks et al., 2012; Lefevre et al., 2015; Möhring et al.,
30 2020; Skevas et al., 2015; Wossink et al., 2000). In this context, the prospect of a potential total ban
31 on glyphosate after 2022 has provided greater impetus for a continuation of the political debate on
32 pesticides in the European Union (EU) (Kudsk & Mathiassen, 2020).

33 Glyphosate is the most widely-used herbicide around the world and including in the EU (EC, 2020). It
34 has been used for many years to kill weeds during the period following the harvest of a crop and
35 before the sowing of the next one in field crops and vegetable crops, and as weed control in the
36 production of perennial plants (arboriculture and viticulture). The high efficiency of glyphosate
37 against perennial weeds means it is greatly appreciated and widely used (Duke et al., 2018).
38 However, scientific evidence has demonstrated its negative impacts on the environment and
39 biodiversity and, more recently, on human health.

40 The renewal of the authorization of the use of glyphosate has been the subject of multiple
41 discussions and debates among decision-makers, citizens, scientists, and agricultural organizations
42 (Kudsk & Mathiassen, 2020). The European marketing authorization for glyphosate, approved by the
43 European Commission (EC) in December 2017 for a period of five years, currently runs until
44 December 15 2022 (EC, 2020). The EU pesticide legislation requires that the approval of all active
45 substances must be periodically reviewed, starting with a scientific assessment by a Rapporteur
46 Member State (extended to four countries: France, Sweden, the Netherlands, and Hungary in the
47 case of glyphosate), and followed by a peer review process overseen by the European Food and
48 Safety Agency (EFSA, 2020). The decision regarding the renewal of the approval of glyphosate will be
49 taken by the EC on the basis of the evaluation reports currently underway.

50 While European decisions were being made, in 2018, the French government presented a
51 glyphosate exit plan to reduce the use of glyphosate-containing products. It has committed to
52 phasing out the main uses of glyphosate by 2020 where alternatives already exist, and by 2022 for all
53 other uses. This relies on European Regulation 1107/2009 (EC, 2009) which stipulates that, “the

54 withdrawal of Market Authorization for a product containing a molecule approved at European level
55 is possible by a Member State if one or more alternative methods, chemical or non-chemical, exist,
56 ensure prevention or control for the same use, and if they are in common use, in principle without
57 any environmental impact and without any major economic impact”.

58 The economic impact of a glyphosate ban has so far received little attention. On a global scale, the
59 issue has been assessed in relation to the potential economic and environmental impacts that would
60 occur if restrictions on glyphosate-use resulted in the world no longer planting genetically modified
61 herbicide-tolerant crops (Brookes et al., 2017). At a European level, the problem is different, since
62 genetically modified crops are rarely used. Alternative weed control methods are known and
63 practiced, at least in organic agriculture. Only a few studies have assessed the potential impact of a
64 glyphosate ban in European countries. Kudsk & Mathiassen (2020) have reviewed the desk studies
65 conducted in Sweden, Germany, the United Kingdom and France that assess the feasibility and
66 impacts of the switch to glyphosate-free weeding methods for arable crops, and shown that the
67 impact depends on the tillage strategies employed. For farms that already plough their soils, the
68 economic impacts would be relatively low or moderate. Based on a bioeconomic modelling
69 approach for Germany (Böcker et al., 2018, 2020) and Switzerland (Böcker et al., 2019), the authors
70 also concluded that the microeconomic impact would be low.

71 Our study focuses on the existence of non-chemical alternatives to the use of glyphosate in French
72 viticulture, and on their economic impact. It goes further than a previous study on glyphosate
73 alternatives in French agriculture (Reboud et al., 2019), which mainly focused on arable crops and did
74 not assess the economic costs of alternatives.

75 French viticulture only covers 3% of the territory, but concentrates 20% of pesticide-uses (herbicides,
76 fungicides and insecticides) (Agreste, 2019). Glyphosate is widely used in viticulture for inter- and
77 intra-row weed control. It is by far the main herbicide used in viticulture (93% of the areas that
78 receive herbicide applications are treated with glyphosate).

79 The quantities of glyphosate used in viticulture vary from 400g to 1000g a.i./ha (Reboud, 2019). They
80 are similar to the quantities used in other cropping systems in France, however vineyards receive
81 glyphosate applications more frequently than annual cropping systems (Reboud et al. 2019). France
82 is among the five EU countries with the highest use of glyphosate in 2017 (> 320 g of a.i. per ha)
83 (Antier et al., 2020).

84 Literature and surveys show that non-chemical alternative techniques do exist, notably in organic
85 vineyards. The effects of organic and conventional practices on weed control have been compared,
86 which suggests that replacing a glyphosate application with cultivation may be an effective method
87 of reducing herbicide-use in vineyards (Baumgartner et al., 2017; Bond et al., 2001; Reboud et al.,
88 2019).

89 In order to reveal what could be the micro-economic impact of a glyphosate ban for French wine-
90 producing farms, the data from a large national survey on crop practices at field level were used to
91 compare the costs of techniques identified for various farms.

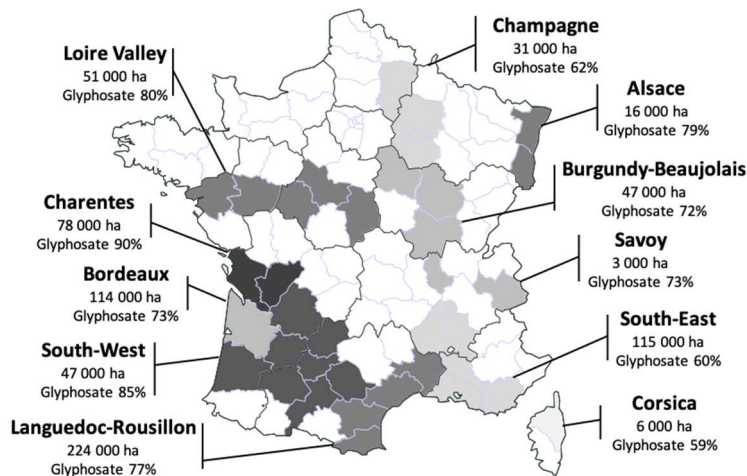
92 This survey allowed us to compare the crop management practices observed at field level for farms
93 that currently use glyphosate and other chemical herbicides, with those of farms that do not use
94 herbicides under similar conditions. An estimation of the costs of the various techniques thus
95 identified made it possible to calculate what the impact would be if farms were to adopt already
96 existing techniques.

97 **1. Materials and Methods**

98 **1.1. Crop management data**

99 In order to obtain data on the weeding practices of winegrowers, we used a survey on farming
100 practices conducted by the French Ministry of Agriculture every four years. This survey (*“Pratiques*
101 *Culturales”*, that is, “crop practices”, a survey of the Statistics and Prospective Analysis Service of the
102 Ministry of Agriculture and Food) covered all major French agricultural production systems, and
103 followed a sampling plan that allowed it to be representative of current farming systems. It aimed to
104 describe the technical practices of crop management and, in particular, the use of phytosanitary

105 products by French farmers. The last survey on viticulture (which is the one used in our study), was
106 carried out in 2017 for the 2015-2016 agricultural campaign (Agreste, 2019). A total of 7,800 crop
107 plots located across 21 wine-producing areas across France (Figure 1) were surveyed, with 7,156
108 questionnaires collected, thus covering an area of 729,424 ha (that is, 93% of the land dedicated to
109 viticulture in France).



110
111 **Figure 1: French wine-producing areas and glyphosate-use**

112 From the database used, we retrieved the following variables for each of the 7,156 plots surveyed:
113 localization, row spacing, type of cover cropping (no cover crop, cover crop in every row, cover crop
114 in every inter-row out of two), and inter-row and intra-row weed control operations. For the inter-
115 rows, we retrieved the number of herbicide applications, the product and quantity used, and the
116 number of mechanical interventions per type of practice, while distinguishing between mowing,
117 tillage using a disc tool, tillage using a pronged tool, and the use of an inter-row rotavator; for intra-
118 row operations, we retrieved the number of herbicide applications, the product and quantity used,
119 and the number of mechanical interventions per type of tool, while distinguishing between inter-vine
120 blades, inter-vine rotary tools and intra-row non-reversible vineyard ploughs. We initially identified
121 nine weed management types, by taking into consideration the use of chemicals (exclusively
122 chemical, exclusively mechanical, and mixed) and the type of cover cropping. Then, we described the
123 cultivation operations for each type.

124 **1.2. Calculation of weeding costs**

125 To calculate the working times and costs of each of the cultivation operations identified, we used
 126 existing data published by extension services. The national data repositories on the costs of
 127 cultivation operations are published each year for the establishment of benchmarks and mutual aid
 128 scales among farmers (APCA, 2018) with information for each type of agricultural machinery.

129 Costs have been estimated for each wine-producing region (V) and weed-management type (TYP)

$$130 \quad CT_{V,TYP} = CH_{V,TYP} + CTool_{V,TYP} + CTtract_{V,TYP} + CLabor_{V,TYP}$$

131 With $CT_{V,TYP}$: total costs; $CH_{V,TYP}$: herbicide costs; $CTool_{V,TYP}$: tool costs; $CTtract_{V,TYP}$: tractor
 132 costs; $CLabor_{V,TYP}$: labor costs

133 Each practice (TYP) corresponds to a succession of interventions on the vine defined by a number of
 134 passages (NP) with a specific tool (I). For each element of the matrix $NP_{(TYP,K)}$ which describes the
 135 number of operations for nine practices and nine tools, we calculated the different costs.

136 We chose the appropriate tool to each operation from the database. The tools differ according to the
 137 distance between the rows, and the benchmarks we used distinguish between tools for wide vines
 138 and tools for narrow vines. Tool costs were calculated based on the price of the equipment (average
 139 price excluding tax), on the depreciation costs calculated on the basis of a rate (linear depreciation
 140 over a lifespan) and on maintenance and repair costs. We calculated the tool depreciation per
 141 hectare on the basis of the observed average vineyard areas of the wine-producing farms in each
 142 producing area.

143 Costs are calculated by adding operations carried for the whole vineyard, for intra row as well as
 144 inter-row areas.

$$145 \quad CTool_{TYP,WV} = [\sum_{TYP,i1=1}^{i1=1} CTool_{WV,i1} * dummy_{WV,i1}] + [\sum_{TYP,i2=1}^{i2=4} CTool_{WV,i2} * dummy_{WV,i2}] + [$$

$$146 \quad \sum_{TYP,i3=1}^{i3=4} CTool_{WV,i3} * dummy_{WV,i3}]$$

147 With :

148 WV : inter- row width (large, narrow vines)

149 I operations : i1 on the whole vineyard; i2 on the row area , i3 on the inter-row area

150 $dummy_{WV,i} = 1$ if tool is selected, 0 if not.

151 Tractor costs and labor costs depend on the working time which itself depends on the tool used, and
152 its speed. Tractor costs include repairs and fuel, and the depreciation based on a number of hours
153 used annually.

$$154 \text{ WT}_{\text{TYP,WV}} = [\sum_{\text{TYP},i1=1}^{i1=1} \text{NP}_{\text{TYP},i1} * \text{Perf}_{\text{WV},i1}] + [\sum_{\text{TYP},i2=1}^{i2=4} \text{NP}_{\text{TYP},i2} * \text{Perf}_{\text{WV},i2}] + [\sum_{\text{TYP},i3=1}^{i3=4} \text{NP}_{\text{TYP},i3} * \\ 155 \text{Perf}_{\text{WV},i3}]$$

156 With Perf : speed of the tool

157 As the working time provided in the database on the costs of cultivation does not include the time
158 related to adjustments, cleaning, getting started, etc., and as the expert and extension service
159 publications consulted state that where new techniques and machinery are not well mastered by the
160 farmers, extra time could be significant: we have thus maintained a common assumption of 30%
161 extra time (Gaviglio, 2013). An hourly working rate of €18/hour, which corresponds to the average
162 skilled labour rate, has been taken into account.

163 **1.3. Impact on farmer income**

164 In order to measure the importance of estimated additional costs in relation to farmer income, we
165 used French data from the Farm Accountancy Data Network (FADN) for wine-producing farms. The
166 French FADN database includes 1,130 wine-producing farms, which constitutes a representative
167 sample of the 43,928 French wine-producing farms, whose annual Standard Gross Product is greater
168 than €25,000. We used three indicators of economic results to compare the costs of shifting from
169 chemical weeding to a non-chemical alternative to its benefits: the Gross Product (total sales of
170 products plus changes in stocks), Gross Operating Profit (Gross Product plus subsidies minus
171 intermediate consumptions, expenses and taxes) and Farm Net Income (total remuneration of fixed
172 factors and entrepreneurial risks in the accounting year). Detailed definitions are available on the
173 FADN website ([https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/farms-
174 farming-and-innovation/structures-and-economics/economics/fadn_en](https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/farms-farming-and-innovation/structures-and-economics/economics/fadn_en)).

175 Finally, we also retrieved channels, prices and yields associated to different weed management
176 strategies from the “*Pratiques Culturelles*” survey information on sales and marketing, so as to shed
177 light on the valorization of herbicide-free practices.

178 **1.4. Sensitivity analysis of the calculation of working time and depreciation**

179 Two sensitivity tests were carried out on our calculations.

180 The first concerns working time. In our basis (scenario H1), a 30% increase in working time with the
181 use of mechanical weeding machines was included. In scenario H2, this increase was not taken into
182 account.

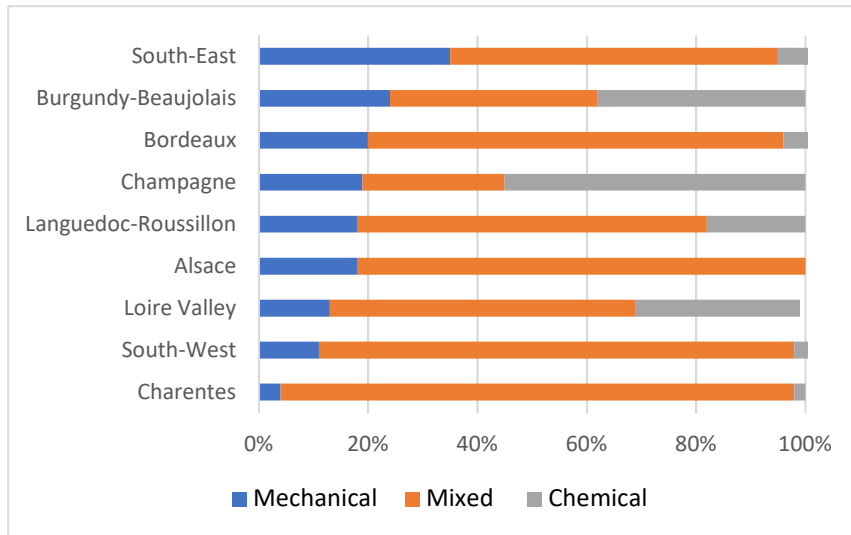
183 The second test (H3) related to the depreciation calculation method, which was no longer carried out
184 on the basis of the size of the farms in each wine-producing area, but on an average wine-producing
185 area of 20 ha.

186 **2. Results**

187 **2.1. Wine-producing areas and weed- control methods**

188 At national level, 80% of the vineyard areas used at least one herbicide in 2015-2016. Glyphosate was
189 used on 75% of the vineyard areas, where it and was the only herbicide to be used on 24% of these
190 cultivated areas, with while another herbicide was used on 51% of these areas. The other top-
191 ranked herbicides were flazasulfuron (28%), aminotriazole (17%) carfentrazone-ethyl (13%),
192 flumioxazine (12%) and glufosinate ammonium (10%). Since then, aminotriazole and glufosinate
193 ammonium have been removed from the French market, in 2015 and 2018, respectively.

194 Three weed control methods categories were identified (Figure 2): exclusively mechanical (20% of
195 the areas), chemical herbicides used on across the whole area (14%), and mixed, which is a
196 combination of intra-row chemical weed control intra-row and inter-row mechanical inter-row weed
197 control (66%).



198

199 **Figure 2: Mechanical, mixed and chemical weeding control methods in as a % of the land area for the main**
 200 **wine- producing areas**

201

2.2. Typology of weeding practices

202

203 We carried out the analysis for all wine-producing areas (with the exception of Corsica and Savoy, for

204 which we had insufficient data). By pooling the plots according to the weed control method and type

205 of cover crop used for each wine-producing area, we identified types of crop practices (Table 1).

206 We observed that the practices were represented differently according to the wine-producing area.

207 In the regions of Alsace, the South-West and Bordeaux, over 80% of the plots surveyed are cover-

208 cropped (entirely or one row out of two), while in Languedoc-Roussillon, the South-East and

209 Burgundy-Beaujolais, where drought conditions are often more pronounced, less than 30% of the

210 plots are cover-cropped. The relative soil surface allotted to cover cropping (for example, every inter-

211 row, one inter-row out of two, etc.) and the type of flora used affects the intensity of the

212 competition for soil, nutrient and water resources exerted on vineyards, but also relates to the risks

213 of erosion and runoff effects, in particular in steep-slope vineyards (Celette et al. 2008; Prosdocimi et

214 al., 2016; Vrsic et al., 2011). The advantages and disadvantages of cover cropping or tillage differ

215 according to soil characteristics, rainfall and drought intensity in France, which are somewhat

216 variable given that wine production occurs under oceanic, Mediterranean and continental climates

217 (Raclot et al., 2009; Ripoche et al., 2011).

218 Mechanical weeding practices are observed in all wine-producing areas, however they are more
 219 frequently used in the South-East and Burgundy-Beaujolais regions.

220 By retaining only the practices that concern more than the 30 plots monitored for each wine-
 221 producing area, we ultimately selected 43 crop practices for the cost estimations (see shaded areas
 222 in Table 1)

223 **Table 1: Distribution of technical management methods as a % of the land area of each wine-**
 224 **producing area and number of plots observed**

	Mechanical			Mixed			Chemical		
	No cover crop	cc	cc 1/2	No cc	cc	cc 1/2	No cc	Cc	cc 1/2
Bordeaux	9%	4%	7%	3%	34%	39%	4%	1%	-
	50	21	37	16	180	205	19	4	-
Alsace	1%	5%	12%	-	29%	53%	-	-	-
	3	13	33	-	77	141	-	-	-
Burgundy-Beaujolais	20%	3%	1%	15%	19%	4%	36%	2%	-
	142	25	5	106	153	27	290	15	-
Champagne	7%	11%	1%	8%	13%	5%	53%	2%	0%
	37	53	6	43	61	26	260	9	1
Charentes	1%	1%	2%	20%	21%	53%	2%	-	-
	5	4	13	107	112	283	10	-	-
Languedoc-Roussillon	12%	5%	1%	44%	13%	7%	17%	1%	-
	108	43	10	334	97	50	147	7	-
South-East	27%	4%	4%	41%	10%	9%	6%	0%	-
	313	58	71	480	168	110	74	1	-
South-West	1%	3%	7%	4%	21%	62%	3%	0%	-
	14	33	77	42	250	583	24	3	-
Loire Valley	6%	6%	1%	3%	33%	20%	28%	2%	-
	62	69	7	69	239	101	181	11	-

225 *Source:* Our calculations are based on “Pratiques Culturales” 2017 data; cc: cover crop, cc ½: one inter-row out
 226 of two is cover-cropped, the other just being bare soil.

227 NB: The grey-shaded cells correspond to a sample that comprises more than 30 plots and that was retained
 228 from the analysis of practices for reasons of statistical representativeness.

229
 230

2.3. Labour and Machinery Cost estimation

231 2.3.1. Working time

232 For each of these 43 “types” of crop management systems, the data relating to the distance between
 233 the rows, the number of operations, as well as the type of machines used made it possible to
 234 calculate the working time of each practice type (Table 2).

235 **Table 2: Working time (in hours per ha)**

	Mechanical			Mixed			Chemical		
	No cc	cc	cc ½	No cc	cc	cc ½	No cc	cc	cc ½
Bordeaux	17.7	-	10.8	-	7.5	6.6	-	-	-
Alsace	-	-	12.6	-	11.2	9.7	-	-	-

Burgundy-Beaujolais	17.1	-	-	13.1	9.5	-	6.4	-	-
Champagne	18.1	19	-	9.8	13.5	-	6.6	-	-
Charentes	-	-	-	11.6	8	8.3	-	-	-
Languedoc-Roussillon	10.5	7.3	-	7.1	5.9	6.3	1.8	-	-
South-East	11.1	9.7	11	8.6	5.9	6.6	1.8	-	-
South-West	-	7.5	8.8	7.1	6.9	6.4	-	-	-
Loire Valley	15.3	16.7	-	10.6	10	9.7	5.8	-	-

236

237 We observed a clear increase in working time when switching from chemical to mechanical weeding
238 in the inter-row (mixed vs chemical) and intra-row (mechanical vs mixed). We also observed that
239 working times are higher in the absence of cover crop. Intra-row (and, to a lesser extent, inter-row)
240 mechanical weed control involves a large number of field operations. Such weed control work is
241 generally carried out between May and July and can compete with other necessary operations (with
242 the level of difficulty of weed control depending on soil conditions). Chemical weed control requires
243 less time and can be carried out at more flexible times. The lack of skilled staff and the difficulty in
244 appointing new workers is mentioned by winegrowers organizations as potential hindrances for a
245 successful transition to non-chemical weeding.

246 Differences among regions are mainly explained by inter-row spacing. Overall, 21% of the vineyards
247 have an inter-row distance of less than 170cm, which refers to the entire Champagne wine-producing
248 area, 96% of the Beaujolais producing area and 94% of the Burgundy producing area. This spacing
249 occurs in only a small area of the Bordeaux wine-producing area (that is, the Pauillac appellation).
250 The time required per hectare for a single operation is greater in vineyards with narrow rows,
251 because of the greater number of rows. In the Burgundy-Beaujolais, Champagne, Loire Valley and
252 Alsace wine-producing areas, vineyards generally have narrow rows and the working time for
253 chemical weed control systems is around 6 hours/ha, which increases to 9 to 13 hours/ha for mixed
254 systems and to 13 to 19 hours/ha for mechanical weed control systems. In the Languedoc-Roussillon,
255 South-East and South-West wine-producing areas, around 2 hours/ha are required for chemical weed

256 control systems, 6 to 8 hours/ha for mixed systems and 7 to 11 hours/ha for mechanical weed
 257 control systems.

258 **2.3.2. Cost estimations**

259 Table 3 shows that the diversity observed in costs for different wine-producing area is significant. The
 260 highest costs are observed for vineyards with narrow rows (in the Champagne, Burgundy-Beaujolais
 261 and Loire Valley producing areas), and mainly reflect the differences in working hours.

262 **Table 3: Costs in €/ha (depreciation excluded)**

263

	Mechanical			Mixed			Chemical		
	No cc	cc	cc 1/2	No cc	cc	cc 1/2	No cc	cc	cc 1/2
Bordeaux	660	-	297	-	298	269	-	-	-
Alsace	-	-	470	-	506	447	-	-	-
Burgundy-Beaujolais	638	-	-	471	459	-	433	-	-
Champagne	673	709	-	445	595	-	450	-	-
Charentes	-	-	-	417	355	356	-	-	-
Languedoc-Roussillon	291	202	-	258	228	320	183	-	-
South-East	307	269	302	300	232	251	184	-	-
South-West	-	207	242	263	273	266	-	-	-
Loire Valley	569	621	-	474	459	426	397	-	-

264

265 The total costs involved (Table 4) include the cost of labour, the use of traction tools and the
 266 depreciation of materials specific to each farming operation. The depreciation of specific equipment
 267 was defined based on the average size of farms in each wine-producing area, as given in the FADN.
 268 The differences in the size of the farms largely accounted for the differences observed in equipment
 269 costs (for example, the high costs per hectare in Champagne and Alsace are related to small vineyard
 270 surface areas per farm).

271 **Table 4: Total costs in €/ha (depreciation included)**

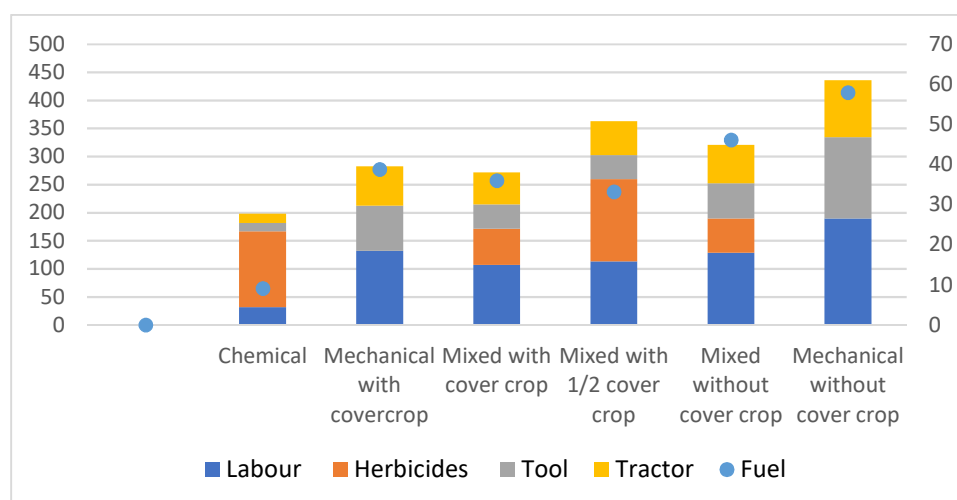
	Mechanical			Mixed			Chemical		
	No cc	cc	cc 1/2	No cc	cc	cc 1/2	No cc	cc	cc 1/2
Bordeaux	779	-	486	-	320	357	-	-	-
Alsace	-	-	1 129	-	615	576	-	-	-
Burgundy-Beaujolais	769	-	-	645	528	-	476	-	-
Champagne	1 072	1146	-	978	1 156	-	584	-	-

Charentes	-	-	-	551	378	499	-	-	-
Languedoc-Roussillon	436	282	-	321	271	363	198	-	-
South-East	526	422	507	387	275	346	199	-	-
South-West	-	265	341	323	295	329	-	-	-
Loire Valley	686	730	-	579	493	487	418	-	-

272

273 Figure 3 illustrates the composition of the total costs for the different management systems in the
 274 Languedoc-Roussillon producing area, which is the most important in terms of vineyard area. We can
 275 observe that labour costs are the main factor for the additional cost of mechanical practices,
 276 followed by the costs of traction tools, which are also directly linked to the working time. The total
 277 fuel consumption in liters /ha is indicated on the second axis of the ordinates and shows a significant
 278 increase in fuel consumption linked to mechanical weed control.

279 The two entirely herbicide-free techniques showed contrasting figures in terms of total costs, as well
 280 as in fuel consumption. Using cover crops has a positive influence on the two indicators.



281
 282
 283
 284
 285

Figure 3: Costs per hectare (broken into bars and expressed in €/ha on the left axis) and fuel consumption (point expressed in liters/ha on the right axis) in the Languedoc-Roussillon producing area

2.4. Sensitivity analysis

286 The additional cost calculated for each wine-producing area corresponds to the difference between
 287 the cost of the most frequently used weed-control method and that of the most widespread
 288 herbicide-free practice with the same inter-row cover cropping method. This additional cost varies
 289 from €12 to €553/ha, depending on the producing area. The additional cost is particularly high in

290 regions where the most widespread weed control technique is chemical weeding (Champagne and
 291 Burgundy-Beaujolais). We chose to base our estimation on the most frequently used weed-control
 292 method. The results would not be exactly the same if we took the second most frequently used
 293 method, but there would be no great difference, except to a certain extent for the Loire Valley where
 294 chemical weeding is also significantly present compared to the mixed weeding method retained in
 295 our calculation.

296 **Table 5: Sensitivity of the additional cost (€) of non-chemical weeding to different**
 297 **hypotheses**

	H 1	H2	H3
	Basic scenario	"Net" working time	Depreciation on a 20ha farm
Bordeaux	129	106	144
Alsace	553	537	205
Burgundy-Beaujolais	293	235	254
Champagne	488	426	272
Languedoc-Roussillon	115	97	120
South-East	139	126	147
South-West	12	-1	16
Loire Valley	237	201	249

298
 299 In Table 5, we can see that the scenario regarding working time (H2 vs H1) does not significantly
 300 change the results obtained. On the other hand, the depreciation calculation method has a strong
 301 impact, in particular, on the wine-producing areas where farms are small-sized (Alsace, Champagne),
 302 since in H3 equipment depreciation is calculated based on a significantly larger farm size than in H1.

303 **2.5. Additional cost and impact on farmer income**

304 The additional cost of replacing chemical weeding with mechanical weeding is compared to the
 305 economic results of farms, issued from the FADN data for each wine area (Table 6). The additional
 306 cost thus represents from 0.3 to 4.4% of the Gross Product (GP), from 1 to 11.5% of the Gross
 307 Operating Profit (GOP) and from 2 to 18% of the Farm Net Income (FNI), depending on the wine-
 308 producing areas. Overall, an average additional cost of €250/ha represents 2.6% of the GP, 7.1% of
 309 the GOP and 10.6% of the FNI. By using the GOP as the most relevant income indicator for our
 310 analysis, the additional cost represents less than 5% of the GOP in several wine-producing areas,
 311 around 7.5% in the Loire Valley and Languedoc-Roussillon, and 11.5% in Alsace. The result for Alsace

312 is essentially related to our hypothesis concerning the calculation of equipment depreciation,
 313 because of the limited vineyard surface area per farm. Using the H3 hypothesis will significantly
 314 change this result for Alsace, with an additional cost that thus represents only 4.3% of the GOP.

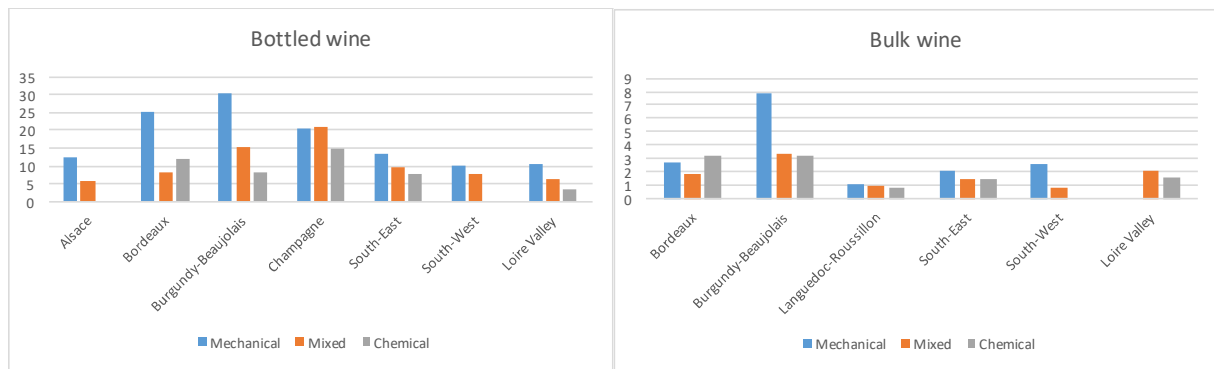
315 **Table 6: Additional cost of mechanical weed control compared to chemical weed control**
 316 **(value and % of economic indicators)**

	Additional cost	GP	GOP	FNI	Additional cost in % GP	Additional cost in % GOP	Additional cost in % FNI
	€/ha	€/ha	€/ha	€/ha			
Alsace	553	12677	4791	3077	4.40%	11.50%	18.00%
Bordeaux	129	11354	2618	1334	1.10%	4.90%	9.70%
Burgundy- Beaujolais	293	19934	7893	5499	1.50%	3.70%	5.30%
Champagne	488	29969	12205	9411	1.60%	4.00%	5.20%
Languedoc Roussillon	115	4834	1486	679	2.40%	7.70%	16.90%
South-East	139	7605	3078	2237	1.80%	4.50%	6.20%
South-West	12	3685	1349	773	0.30%	0.90%	1.60%
Loire Valley	237	9797	3227	2081	2.40%	7.30%	11.40%

317 Source: Our calculations based on "Pratiques Culturelles" 2017 and average FADN data for 2015-2016-2017 for vineyards.
 318 NB: The insufficient amount of data available concerning herbicide-free weed control for the Charentes producing area
 319 does not allow us to consider this area in our estimations. GP: Gross Product; GOP: Gross Operating Profit; FNI: Farm Net
 320 Income.

322 2.6. Marketing channels and wine prices

323 The majority of the grapes harvested by winegrowers are paid per liter of wine produced (77%), the
 324 rest being paid either according to the degree of alcohol (Cognac) or per kilo of grapes. Winemakers
 325 can sell bottled wine or bulk wine, and wine prices will differ accordingly, however, prices also differ
 326 according to the geographical areas of production (or "appellation") and to the specifications of the
 327 production methods (that is, organic or biodynamic farming, among others). Over 50% and up to
 328 97% of the wine is sold in bottles in Bordeaux, Alsace and Champagne, whereas bottled wine
 329 represents less than 30% in the Languedoc-Roussillon, South-East and South-West regions. Figure 4
 330 shows the prices in €/liter for bottled wine and bulk wine, according to the weed control practices
 331 previously identified. We observed that the prices for wine produced without the use of herbicide is
 332 sold in almost all cases at a higher price than the wine produced using chemical herbicides (either
 333 mixed or chemical only). This difference reflects the fact that in areas with an appellation, it is
 334 possible to value the efforts made in the management of vineyards, including weeding practices, for
 335 example.



336

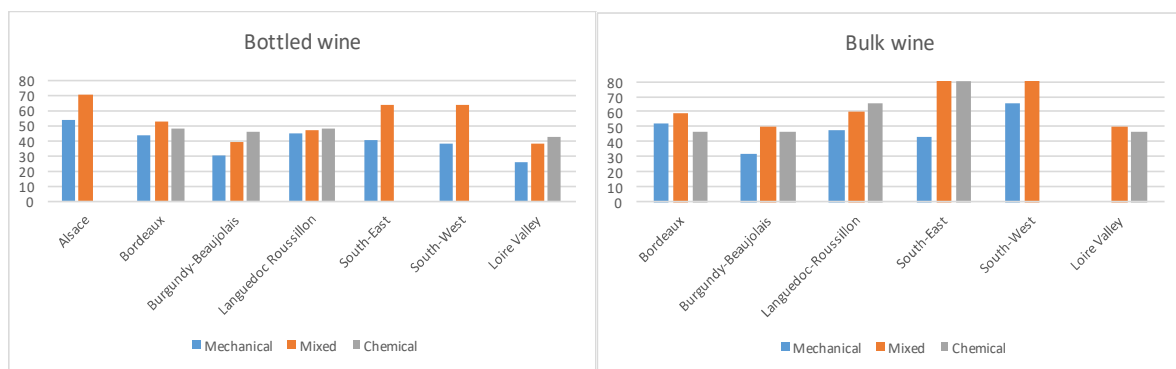
337 **Figure 4: Wine price €/liter for bottled wine and bulk wine according to weed management method**

338 Part of the differences in price is, however, correlated with the variations in the maximal production

339 per hectare that can be certified under the appellation. As a result, the benefits of higher prices

340 compensate for the lower volumes produced (see Figure 5). Weeding practice is therefore only one

341 component of the differences between the different situations.



342

343 **Figure 5: Yields in hectoliter /ha for bottled wine and bulk wine according to weed management methods**

344 3. Discussion

345 3.1. Mechanical weeding and its impact on vine growth

346 Even if the lower yields for mechanical weeding observed in Figure 5 are mostly due to the maximal

347 production per hectare that can be certified under the appellation, we can question the negative

348 impact of mechanical weeding on vineyard productivity; an issue that is often highlighted by farmer

349 associations as an obstacle to adopting mechanical weeding methods. There are relatively few

350 references on this issue. One study (Sanguaneko et al., 2009) shows that the impact of alternative

351 techniques compared to herbicide treatment can be negative in a dry year, especially in the case of

352 cover crops. Most experts agree that mechanical weeding depends on the mastery of the technique.

353 Poor technical skills applied to mechanical weeding operations may certainly cause damage to the
354 vine stocks and disrupt the surface root system, which can lead to yield losses. During the transition
355 from glyphosate to non-glyphosate-based weed control methods, the vines will reorganize their root
356 systems to a greater depth. The time required to reach a new equilibrium may vary, depending on
357 the physiological state of the vine, soil-climate conditions and yield objectives. Nonetheless, tests
358 show that not all varieties are affected in the same way, though it remains extremely challenging to
359 determine what is due to the grape variety, the vigor of the chosen rootstock, the methods of
360 implantation and the corrective actions taken (Gaviglio et al., 2013). When mechanical weeding is
361 used in young vineyards, the vine stocks will set their roots at a depth adapted to mechanical
362 weeding techniques.

363 **3.2. Mechanical weeding and weed flora**

364 The underlying hypothesis in the direct comparison of glyphosate versus mechanical weed control, as
365 seen in the present study, concerns the stability of the weed flora. This hypothesis, however, may be
366 wrong. If the flora changes over time under mechanical weeding, it may be easier (or more difficult)
367 to control. Fried et al. (2019) showed a limited effect of chemical versus mechanical weed control on
368 species composition, with a few specialized species, a more diverse weed flora with more annual
369 species under mechanical weeding, and less troublesome weeds along the rows in three wine-
370 producing areas in France. This confirmed the findings of Steenwerth et al. (2010) in California, who
371 also documented a limited modification of the weed seed bank. The limited impact on weed flora
372 with more annual species and less troublesome weeds suggests that the transition should not lead to
373 more difficult weed management and/or extra costs.

374 The absence of herbicide-use will also lead to a change in inter-row management with a lower
375 frequency of bare soil, and more cover crops. Indeed, cover crops can have a positive impact on soil
376 carbon content, on the consequences for soil fertility (Guzman et al., 2019), and on biodiversity and
377 the provision of ecosystem services (Garcia et al., 2018; Hoffmann et al., 2017; Richards et al., 2020;
378 Winter et al., 2018). One limitation of the more widespread use of cover crops, however, concerns

379 water availability in dry areas during summer, and it remains a challenge to find cover crops suitable
380 to vineyards in these areas (Messiga et al., 2016; Sweet et al., 2010)

381 **3.3. Why do some farmers adopt alternative weeding techniques when they are** 382 **more costly than chemical weeding?**

383 As we have seen, the majority of farmers only use herbicides below the row and a number of them
384 do not use any herbicides at all. This is despite the additional costs that we have calculated.
385 Therefore, what are the reasons for this discrepancy?

386 First, aid for investment in specific equipment that contributes to the agro-ecological transition
387 currently exists, though due to a lack of homogeneous data we have not included it in our
388 calculations. Such aid comes from the French “Farm competitiveness plan”, co-financed by the
389 European Agricultural Fund for Rural Development (EAFRD), the State, and regional authorities. It
390 usually covers up to 40% of the value of the equipment purchased.

391 Secondly, the working time included in our analyses corresponds to skilled and paid working time
392 valued at market price. However, the share of family work represents 46% of the total labour force of
393 wine-producing farms on average (FADN). The additional labour required for mechanical weeding
394 techniques is not necessarily valued by the farmer in the same way as if employees were to be hired.

395 Finally, herbicide-free practices are often included in the production methods associated with the
396 specifications of designations of origin or organic production. Consumers are indeed willing to pay
397 more according to these specifications. (Schäufele et al., 2017; Sellers-Rubio et al., 2016). In our case,
398 we cannot attribute the price difference observed solely to the difference in the weeding method, as
399 other plant protection aspects are also contained in the specifications. It is therefore difficult to
400 attribute the part of glyphosate-free weeding practices in the additional costs and price difference
401 observed in Figure 4. However, we believe that it plays a significant role for a certain number of
402 farmers.

403 Other non-economic motivations, particularly those that may be linked to environmental
404 preferences, may also be important for some winegrowers (Lozano-Vita et al., 2018). The collective

405 dimension of behaviors (such as the behavior observed by different farmers involved in a single
406 cooperative committed to an environmental approach) should also be taken into account, and recent
407 research shows that the intention to reduce pesticide-use is strongly determined by whether or not
408 other farmers also act in the same way (Bakker et al., 2020).

409 **3.4. Glyphosate ban vs other policies**

410 The difficulties in the adoption of alternative techniques as highlighted by farmer organizations have
411 led to the postponement of the deadlines for totally banning glyphosate at both national and
412 European levels. This raises questions concerning other public policy instruments that could be put in
413 place, either instead of the ban, or to support producers in a gradual change of practices whilst
414 waiting for the ban to be implemented.

415 From the point of view of economic theory, taxation is the most appropriate instrument because it
416 allows negative externalities to be internalized into the price and the decisions made by farmers. If it
417 is accompanied by a redistribution of the tax revenue to farmers, it can globally have a no effect on
418 farmer incomes. One of the criticisms of the tax is that, given the low elasticity of pesticides (Skevas
419 et al., 2013), extremely high tax levels are required to achieve a significant reduction. This is because
420 there is no easily implementable substitute, even if herbicides are found to be more elastic, as
421 mechanical alternatives are available. In the case of taxation, a targeted re-distribution of tax
422 revenues to farmers is thus crucial to create leveraged effects on pesticide-use, and to increase the
423 acceptability of pesticide taxes (Böcker et al., 2016; Jacquet et al., 2011). Furthermore, differentiated
424 taxation schemes, according to the hazard associated with each pesticide, could be implemented to
425 reduce risks caused by pesticide-use (Finger et al., 2017). A glyphosate tax with redistribution to
426 support the adoption of alternatives could thus be a suitable option.

427 Among the public policies that may help to modify agricultural practices, the agri-environmental
428 schemes (AES) are an important component of the European agri-environmental policy. One study
429 shows how the adoption of AES by French winegrowers has contributed to a decrease in the use of

430 herbicides within a range of 38 to 53% below usual consumption levels (Kuhfuss et al., 2018). This
431 clearly indicates that support to compensate for additional costs is efficient.

432 Policy targets are critical tools for providing strong and persistent signals to all stakeholders. It is thus
433 important to encompass all stakeholders across the food value chain in any future policies. Pesticide
434 policies should thus be articulated with other policies that target the different issues, and by
435 stakeholders involved in pesticide reduction (Möhring et al., 2020). In our case, labelling and
436 information for consumers are part of the solution.

437 **Conclusion**

438 Our analyses show that the main difficulty for vine growers in the removal of glyphosate is the intra-
439 row weeding of vines. We have shown that the additional cost of herbicide-free techniques averaged
440 €250/ha, and varied from €12 to €550/ha, depending on the wine-producing area. The working time
441 and the purchase of new equipment are the two main reasons for such additional costs. The
442 remuneration of the workforce accounted for in the costs could be lowered if farmers or their family
443 carry out certain farming operations themselves. Certain winegrowers already benefit from the
444 possibility of promoting the non-use of chemical herbicides, either by means of an individual
445 approach via a direct increase in the price per bottle of wine (independent winemakers), or by using
446 a collective approach via environmental certification (specifications implemented by winemaking
447 cooperatives).

448 In order to facilitate the transition towards a total glyphosate ban, we suggest three measures : 1)
449 giving agro-industrial firms sufficient time to produce alternative mechanical tools; 2) strengthening
450 governmental support to finance new investments; and 3) labelling the production methods that
451 justify the associated higher prices for consumers.

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Costs and fuel consumption per ha
in the Languedoc Roussillon producing area

