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Diagnosis of agrochemical inputs in sugar beet (*Beta vulgaris* L.) fields in the irrigated perimeter of Tadla, Morocco

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Abstract: In Morocco, the irrigated perimeter of Tadla (IPT) is one of the regions most exposed to agricultural contaminants due to agricultural intensification. That study aims to establish a diagnosis of the employment of agrochemicals in the sugar beet crop (*Beta vulgaris L.*) at IPT. Accordingly, we examined agrochemical use data collected in consultation with 148 beet growers for a single agricultural campaign (2020-2021). Data proceeding results indicate five classes of agrochemicals in use in sugar beet fields: fertilizers (95.37%), pesticides (3.51%), adjuvants (0.1%), pH regulators (0.02%), and plant growth promoters (1%). Pesticides are applied in 97.29% of fields; they consist of insecticides (76.35%), herbicides (21.22%), and fungicides (2.43%). Chlorpyrifos, metamitrone, and epoxiconazole are the most used pesticides in the surveyed fields. Underuse and excessive use of pesticides were highlighted as two main modes indicatives of pesticide use trends in the surveyed fields. Excessive use of pesticides can lead to groundwater contamination. For this reason, managing weeds, pests, and pathogens in sugar beet fields needs to envisage other control alternatives to minimize the environmental impact of pesticides, particularly in the current context of water scarcity experienced by the irrigated perimeter of Tadla.

Keywords: Sugar beet (*Beta vulgaris L.*); Pesticides; The irrigated perimeter of the Tadla; Agrochemical input; Crop.

1. Introduction

In Morocco, the sugar beet crop occupies a strategic position in the irrigated perimeter of Tadla (PIT). Indeed, it covers an area of 12,500 ha within the perimeter, ensuring the production of 880,000 tons and allowing the production of up to 110,000 Tons of white sugar, with a contribution of 22% to national production [1]. The vegetative growth of sugar beet is influenced by soil type, site properties (field size), and production factors such as fertilization, pesticide use, and annual conditions relating to climatic conditions during the crop cycle [2–5]. Vulnerability to pests, pathogens, and weeds can constrain good yields [6,7]. The sugar beet crop has a wide range of enemies, causing yield losses ranging from 80% to whole loss of production [8,9]. In agreement with integrated management principles, chemical control of enemies remains effective for eradicating enemies that threaten crop yield [10]. However, the tendency to use pesticides in sugar beet fields in IPT remains unknown. It needs to be investigated in this agricultural area, renowned for being one of the best sugar beet production areas at the national level [11].

Intensive agriculture has achieved satisfactory results in increased agricultural yield but to the detriment of sustainable use of natural resources [12,13]. Its high potential for agricultural production characterizes the IPT, but it remains a fragile ecosystem because of excessive use of water resources [14] and climatic hazards often characterized by water deficits [15]. The acute use of aquifers associated with the increasing use of fertilizers observed at the IPT leaves this agroecosystem facing two main challenges: i) an insufficient water resource [15], ii) threatened by the deterioration of its quality consequential to the frequent and excessive use of fertilizers [16–18]. Assessing the intensification impact of sugar beet is necessary to advance concerns and future challenges for the sugar beet crop and the agroecosystem of IPT. This work evaluates agrochemical input uses, particularly pesticides, due to the intensification of sugar beet crops within the IPT. To this end, the trend in the use of agricultural inputs, including pesticides, is obtained by collecting data on their use through interviews with beet growers during the 2020 – 2021 cultivation campaign in (Sidi Jabeur) a rural municipality of the IPT. This study aims to advance

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our understanding of currently used pesticides in sugar beet crops to safeguard the irrigated perimeter of the Tadla agroecosystem.

2. Experimental

Survey: Data on agrochemical inputs used in sugar beet fields in the rural municipality of Sidi Jabeur (Fig. 1) were collected via questionnaires from 148 farmers during the 2020-2021 agricultural campaign. The farmers were selected based on their cooperativeness, acceptability, and as beet growers having cultivated this crop for the 2020 – 2021 agricultural campaign. The survey began during the sugar beet harvesting season in the rural municipality of Sidi Jaber, and farmers were asked about used agrochemicals (product names and amount) from the start to finish of the agricultural campaign to identify all the products applied by beet growers on their farms from sowing to harvest. The survey was carried out face-to-face with beet growers. The study's objective was explained to the farmer before the start of the survey. All the data collected from the survey of agrochemical products applied during the entire sugar beet cycle have been analyzed. The products used were first reported by category to provide an overview of the consumption of sugar beets in agrochemical products. All the products reported by each farmer are considered in the statistical processing. All agrochemicals reported are considered for analysis, which was carried out using SPSS software. Descriptive statistics (effective and frequencies) were obtained to characterize the population of beet growers in terms of the categories of agrochemical products applied. The products in each category of agrochemicals were characterized by the total quantity reported after processing all of the beet growers' data and by the number of users. For the 'Fertilizers' category and its types, descriptive statistics (mean, median, minimum, and maximum) were obtained to inform on the trend of use of this category, in addition to the quantity and number of users. For the category of pesticides, their regulatory status, composition, and targets were identified from the online phytosanitary index set up by the Ministry of Agriculture, Maritime Fisheries, Rural Development and Water and Forests of Morocco [19], while their families and modes of action have been identified from the Pesticide Properties Database [20]. The trend in the application of pesticides was characterized in terms of the overall quantity applied by all the beet growers surveyed by type of pesticide, by pesticide products marketed, and by the number of pesticide users. Finally, a comparison was conducted to inform of the agreement on applying pesticides concerning the recommended doses.

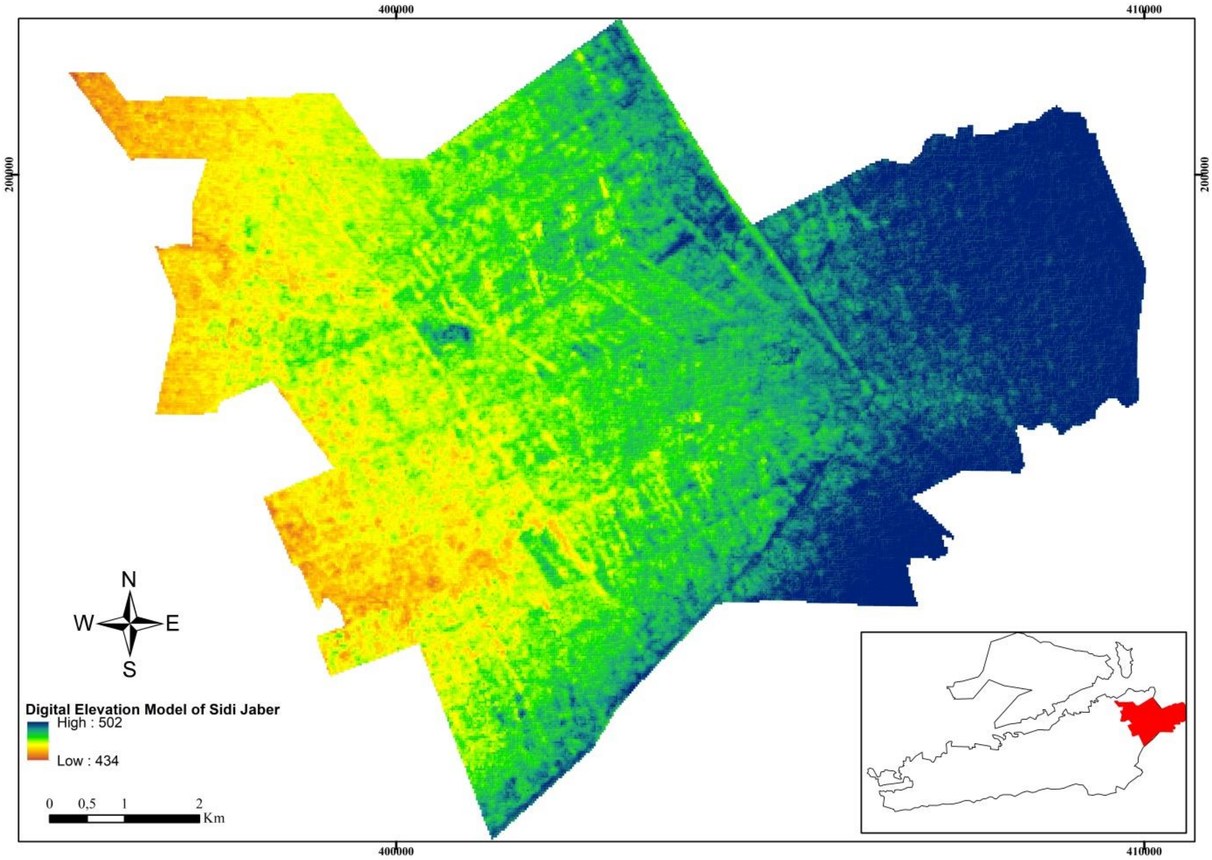


Figure 1. Elevation map of the rural community of Sidi Jaber in the irrigated perimeter of Tadla

Study zone: The rural municipality of Sidi Jabeur has an agricultural vocation, and it is characterized by an area of sugar beets that covers 360 ha. The rural commune of Sidi Jabeur, located within the IPT (Fig.1), has a functional agricultural area of 10,083.47 ha. It is almost dominated by the irrigated area, which is represented by 9883.47 ha. The predominant soils are subtropical brown isohumic soils favorable for crop development under irrigation conditions because of their balanced texture. Temperatures are low in winter, causing morning frosts, and high in summer, with frequent waves of hot and dry wind. The rural commune of Sidi Jabeur is exploited by 2054 farmers, including 1674 in irrigated and 380 in rainfed agricultural zones. It is irrigated from the Bin El Ouidane dam and the Ain Asserdoune spring. In the study area, water table exploitation is done through 548 wells. Farmers in the Sidi Jabeur area have significant traction equipment of around 170 tractors (i.e., a ratio of 22 ha/tractor) with the presence of substantial and diversified support equipment (disc ploughs, ploughshare plow, chisel, cover crop, surfacer, atomizers, combine harvester), which is sufficient to carry out the various agricultural operations (soil work, treatment, harvest) [21].

3. Results

3.1. Consultations with beet growers for the data collection on agrochemicals in use

The agrochemical inputs used in sugar beet fields are divided into five classes: fertilizers, pesticides, plant growth promoters, adjuvants, and pH regulators (Tab.1). The total quantity of agrochemical inputs used in the entire surveyed area (approximately 333 ha) is around 202,150.61 kg. Fertilizers are the most used inputs (i.e., 96% of the total quantity of inputs), followed by pesticides with a proportion of only 3.51%. The other input classes are not abundantly used.

Approximately 14% of sugar beet fields used all input classes to manage sugar beet crops. Pesticides are applied in 144 fields out of 148 (i.e., 97.29% of fields), 57.63% of which use a combination of herbicides, insecticides, fungicides, adjuvants, and fertilizers. About 96% of beet fields use insecticides, 60.81% use fungicides, and 92% use herbicides.

Table 1. Distribution of agrochemical inputs used in sugar beet crop in the PIT in the 2020-2021 campaign.

Agrochemical input classes		Quantities (kg)	
		Detail (kg)	Total (kg)
Fertilizers	Fertilizers Nitrogen fertilizers	61000	
		131800	192 800
Pesticides	Insecticides Herbicides Fungicides	5425,45	
		1508,41	
		172,75	7107.61
Adjuvants			200
pH regulators			55
Plant growth promoters			1988
Total quantities			202 150.61

3.2. Fertilizers

Fertilizers are used in 132 (89.18%) sugar beet fields for a total quantity of around 192,800 kg. The mineral and nitrogen fertilizers used are 13-23-13S-6SO3 and ammonium nitrate (33.5%). 10.14% of fields apply only mineral fertilizers, 45.27% apply only nitrogen fertilizers, 33.78% apply both fertilizer types, and 10.81% do not. Mineral fertilizers are used with an average quantity of 287 kg/ha and minimum and maximum quantities of 25 kg/ha and 1600 kg/ha (Table 2). The average amount of nitrogen fertilizers used is 486 kg/ha. The minimum and maximum quantities reported by sugar beet growers are around 16.66 kg/ha and 1000 kg/ha (Table 2).

Table 2. Characterization of fertilizers application in sugar beet fields in the 2020-2021 campaign. DR: recommended dose; Min: minimum quantity applied per. Ha; Max: maximum quantity applied per. Ha; Med: median).

Fertilizers	Formula	DR (kg/ha	Min (Kg)	Max (Kg)	Med (Kg)	Mean (Kg)	Quantity (Kg)
Mineral Fertilizers	13-23-13S-6SO3	400	25	1600	200	287,53	61000
Nitrogen Fertilizers	Ammonitrate 33.5%	450	16,66	1000	450	486,32	131800
Total Quantity							192800

3.3. Plant growth promoters

Beet growers report other growth nutritive elements. Ten (10) products were utilized to promote the vegetative growth of sugar beet, including humic acids (Humavert, Green Diamond), boron (Kembore, Orbore, Bormax Foliairel, and Tradebor), and other plant growth promoters (Delfan V, Tecamin plus and Perfectorse) (Table 3). The total quantity of plant growth promoters applied in surveyed fields is around 1988 kg. These agrochemical inputs are applied in 80 beet fields, 33 using 2 to 7 products, and 47 applying a single product.

Table 3. Types, quantities, and user numbers of plant growth promoters applied in sugar beet crop at IPT in the 2020-2021 campaign.

Plant growth promoters	Users	Quantity (kg)
Bormax Foliairel	2	20
Delfan V	3	5
Green Diamond	51	1580
Humavert	1	10
Kelpak	23	67
Kembore	37	183
Orbore	3	24
Perfectorse	3	40
Tecamin plus	8	26
Tradebor	6	33
Total quantity (kg)		1988

3.4. pH regulators

PH regulators are applied to the soil to remedy the salinity of healthy water, which will likely impact the absorption of fertilizers and trace elements in sugar beet crops (Table 4). These agrochemical inputs are applied in 37 beet fields for a total quantity of 55 kg.

Table 4. Products, quantities, and user numbers of pH regulators applied in sugar beet crop at IPT in the 2020-2021 campaign.

pH regulators	Products	Users	Quantity (kg)
	Acifast colour	22	28
	Kemilis	6	14
	Neutral Ph	11	13
Total quantity (kg)			55

Table 5. Products, quantities, and user numbers of adjuvants applied in sugar beet crop at IPT in the 2020-2021 campaign.

Product	Composition	Properties	Users	Quantity (Kg)
Arado 1L	Esterified Colza oil (636g/L)	Adjuvants	14	28
Golden mirowet 1L	Nonyl phenol polyglycol ether(525g/L)	Adjuvants for herbicides	26	45
Transit 1L	Lecithin of soybean (355 g/L)	Adjuvants for herbicides	91	127
Total quantity (kg)				200

3.5. Adjuvants

Adjuvants promote the action of pesticides. Sugar beet growers use adjuvants to increase the action of herbicides by keeping them attached to weed leaves. A minority of beet growers use adjuvants with fungicides. The use of adjuvants concerns 108 beet fields surveyed with a total quantity of 200 kg. The products used by sugar beet growers are listed in Table 5

3.6. Pesticides

The annual consumption of pesticides during the 2020-2021 agricultural campaign is around 7106.61 kg over an area of 333 Ha. Insecticide use dominates with a quantity of 5426.2 kg. Herbicides are used with an amount of 1508.41 kg, and fungicides are used with 172.75 kg.

3.6.1. Regulatory status: Data proceeding results indicate the use of twenty-one (21), fifteen (15), and eight (8) registered product labels, respectively, of insecticide, herbicide, and fungicide types (Table 6). All pesticides are registered for use in sugar beet crop [19]. They have varied approval durations, providing sugar beet crops with sufficient chemical treatment products.

3.6.2. Composition*:* The active ingredients can be involved in the composition of a single or several registered product labels. A registered product label may comprise a single pesticide (active ingredient) or an assembly. Pesticide can be applied against a single enemy or generalized to fight a spectrum of enemies.

The insecticides chlorpyrifos and cypermethrin are used in the composition of several products marketed under different names (Table 6). The insecticide lambda-cyhalothrin is involved in the composition of 3 registered product labels; cypermethrin is engaged in the composition of 4 registered products. In contrast, chlorpyrifos is involved in composition 6 (CORDUS, DURSBAN, KEMABAN, KO, LORSBAN, CRATER). These insecticides are applied in the control of a range of pests that are most widespread in IPT sugar beet fields, such as *Agrotis ipsilon*, *Conorhynchus mendicus*, *Cassida vittata*, *Spodoptera littoralis*, *Pegomya beta*, and *Heterodera schachtii*.

Four registered products are formulations of a mixture of herbicides. Three combine desmedipham, ethofumesat, and phenmedipham as products (BETANAL EXPERT, BETASANA TRIO, BISON). Metamitron is compounded in 3 registered products (GOLTIX, MITO, TWISTER), ethofumesat in 5, and desmedipham and phenmedipham are compounded in 3 registered products with modified concentrations. Herbicides applied in surveyed sugar beet fields are used against grasses or broad weeds in the post-emergence period of sugar beet plants (Table 6).

ACANTO PLUS and REX DUO are formulations of two fungicides (Table 6). Epoxiconazole fungicide is compounded in 3 commercial products (OPUS, BACHLOR, REX DUO). Fungicides are used in surveyed sugar beet fields against various pathogens, such as rust, cercosporiosis, and oidium. Their treatment in surveyed fields occurs after the appearance of disease symptoms on the sugar beet leaves.

Table 6. The regulatory status of pesticides used in sugar beet fields in the IPT [19]. DR: Recommended dose.

Registered product label	Active ingredient Composition	Pests, Pathogens, and weeds	RD	Expiration date
AVAUNT	Indoxacarb (150 g/L)	*Conorhynchus mendicus, Cassida vittata,*	1/4 L/ha	28-12-2026
CASALPHA	Alpha-cypermethrine (100 g/L)	*Cassida vittata, Heterodera schachtii*	1/10 L/ha	25-12-2028
FORCE 0.5G	Tefluthrine (50 g/kg)	*Agrotis sp., Heterodera schachtii*	20 kg/ha	19-12-2022
FURY	Zeta-cypermethrine (100 g/L)	*Agrotis sp., Cassida vittata, Conorhynchus mendicus,*	1/4 L/ha	24-09-2024
KARATE 5 EC	Lambda-cyhalothrine (50 g/L)	*Spodoptera littoralis, Cassida vittata*	1/4 L/ha	25-09-2023
OSMOZE	Lambda-cyhalothrine (50 g/L)	*Agrotis sp*	1/4 L/ha	Expired
REEVA	Lambda-cyhalothrine (50 g/L)	*Spodoptera littoralis, Agrotis sp., Cassida vittata,*	1/4 L/ha	18-12-2023
TAIKOK	Cypermethrine (250 g/kg)	*Agrotis sp., Cassida vittata, Conorhynchus mendicus,*	1 L/ha	27-12-2027
BRIGADA GEO	Bifenthrine (40 g/Kg)	*Conorhynchus mendicus, Heterodera schachtii, Agrotis*	10 kg/ha	Expired
COLUMBO	Cypermethrine (8g/L)	*Spodoptera littoralis*	15 kg/ha	Expired

CORDUS	Chlorpyriphos-Ethyl (500g/L), cyperméthrine	*Spodoptera littoralis, Heterodera schachtii*	1L/ha	Expired
DURSBAN	Chlorpyriphos-Ethyl (480g/L)	*Conorhynchus mendicus, Cassida vittata, Heterodera*	5 kg/ha	Expired
JADARM	Methomyl (250 g /kg)	*Cassida vittata*	1 L/ha	Expired
KEMABAN	Chlorpyriphos-Ethyl (100 g/L)	*Cassida vittata*	1L/ha	Expired
KEMABAN	Chlorpyriphos-Ethyl (480g/L)	*Cassida vittata*	1L/ha	Expired
KO	Chlorpyriphos-Ethyl (500 g/L), cypermethrine (50 g/l)	*Cassida vittata*	1 L/ha	Expired
LORSBAN	Chlorpyriphos-Ethyl (50 g/L)	*Conorhynchus mendicus, Heterodera schachtii, Agrotis*	20 kg/ha	Expired
NUMECTIN	Abamectine (18 g/L)	*Pegomya beta*	1 L/ha	23-06-2031
VANTEX	Gamma-cyhalothrine (60 g/L)	*Cassida vittata, Conorhynchus mendicus*	1/4 L/ha	23-06-2031
VITNAM	Methomyl (200 g/L)	-	1 L/ha	26-03-2024
CRATER	Chlorpyriphos (50 g/kg)	*Agrotis sp.*	15 kg/ha	Expired
AGIL	Propaquizafop (100 g/L)	Grass herbicide	1 L/ha	26-03-2024
AKODIM	Clethodim (120 g/L)	Grass herbicide	1 L/ha	01-04-2028
BETANAL EXPERT	Desmediphame (71 g/L) , ethofumesate (112 g/L) ,	Broadleaf weed herbicide (post-emergence)	1 L/ha	16-12-2025
BETASANA TRIO	Desmediphame (15,5 g/L) , ethofumesate (115 g/L),	Broadleaf weed herbicide (post-emergence)	1 L/ha	25-12-2028
BISON	Desmediphame (50 g/L), ethofumesate (200 g/L),	Broadleaf weed herbicide (post-emergence)	1/2 L/ha	28-12-2026
DEVIN	Cycloxydime (100 g/L)	Grass herbicide	1 L/ha	10-07-2028
FUSILADE FORTE	Fluazifop-P-butyl (150 g/L)	Grass herbicide	3/4 L/ha	18-12-2023
GALLANT SUPER	Haloxyfop-R-méthyl ester (104 g/L)	Grass herbicide	1/4 L/ha	18-12-2023
GOLTIX	Metamitrone (900 g/kg)	Broadleaf weed herbicide (post-emergence)	1 L/ha	24-03-2031
MITO	Metamitrone (700 g/kg)	Broadleaf weed herbicide (post-emergence)	1 L/ha	21-06-2027
OBLIX	Ethofumesate (500 g/L)	Broadleaf weed herbicide (post-emergence)	1 L/ha	25-12-2028
SAFARI	Triflusulfuron-méthyl (500 g/L)	Broadleaf weed herbicide (post-emergence)	60 g/ha	28-12-2026
SELECT SUPER	Clethodim (120 g/L)	Grass herbicide	1 L/ha	24/03/2031
VENZAR	Lenacil (800g/kg)	Broadleaf weed herbicide (post-emergence)	400 g/ha	18-12-2023
TWISTER	Ethofumesate (150 g/L), metamitrone (350 g/L)	Broadleaf weed herbicide (post-emergence)	1 L/ha	25-09-2029
ACANTO PLUS	Cyproconazole (80 g/L), picoxystrobine (200 g/L)	Mildew, Cercosporiosis	0,5 L/ha	29-06-2026

EMERALD	Tetraconazole (125 g/L)	Cercosporiosis, Mildew	1 L/ha	28-12-2026
GARDNER	Difenoconazole (250 g/L)	Cercosporiosis	1 L/ha	24-12-2024
THIOGRI	Thiophanate methyl (700 g/L)	Cercosporiosis	1/2 L/ha	24-12-2024
TRESOR	Difenoconazole(250 g/l)	Cercosporiosis, Mildew	1/2 L/ha	24-12-2024
REX DUO	Epoxiconazole (187 g/L), thiophanate methyl (310 g/L)	Cercosporiosis, Mildew	1/2 L/ha	Expired
BACHLOR	Tetraconazole	Cercosporiosis, Mildew	1/4 L/ha	Expired
OPUS	Expoxiconazole (125 g/L)	Cercosporiosis	1 L/ha	Expired

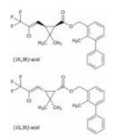
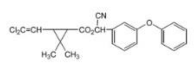
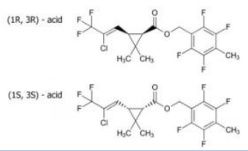
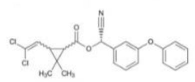
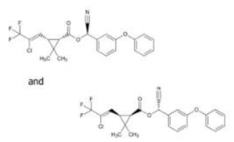
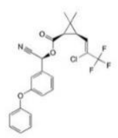
3.6.1. Mode of action: Pesticides in sugar beet fields belong to different chemical families. They can act systemically or through contact with distinctive modes of action.

The 11 insecticides used (Table 7) belong to five families, including pyrethroids (seven insecticides), oxadiazine (one insecticide), carbamates (one insecticide), organophosphates (one insecticide), and avermectins (one insecticide). The insecticides act through three main modes of action, namely sodium channel modulators (all insecticides of the pyrethroid family), disruptors of essential functions (nervous, gastric, or respiratory), and cholinesterase inhibitors (organophosphate families and carbamates [20,22].

The eleven (11) herbicides used in sugar beet fields belong to the respective families: aryloxyphenoxypropionates (two herbicides), uracils (one herbicide), cyclohexanediones (two herbicides), sulfonylureas (one herbicide), benzofurans (one herbicide), triazinones (one herbicide) and carbamates (two herbicides) (Table 8). Those from sulfonylurea, aryloxyphenoxypropionate, and cyclohexanedione families act primarily as acetyl-coA carboxylase inhibitors. Other modes of action, such as photosynthesis inhibition (triazinone, uracil, and carbamate families) and lipid synthesis inhibition (cyclohexanedione and benzofuran families), are also used to control weeds [20,22].

The used fungicides disrupt membrane functions, inhibiting mitosis and cell division, disrupting lipid metabolism, inhibiting respiration, and disrupting nucleic acid synthesis (Table 9). The six (6) fungicides used belong to 3 families, including triazoles (four fungicides), strobilurins (one fungicide), and carbamates (one fungicide) [20,22].

Table 7. Modes of action of applied insecticides at IPT in the 2020-2021 agricultural campaign [20].

Chemical Structure	**Mode of action**	**Chemical Structure**	**Mode of action**
Pyrethroid insecticides			
	A modulator of sodium channel		A blocker of voltage-dependent sodium channel
Bifenthrin		Alpha-cypermethrin	
	A modulator of sodium channel		A modulator of sodium channel
Tefluthrin		Zeta-cypermethrin	
	A modulator of sodium channel and disrupts nerve function		A modulator of sodium channel
Lambda-cyhalothrin		Gamma-cyhalothrin	

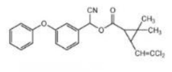
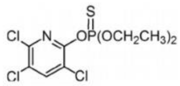
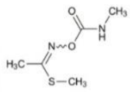
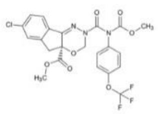
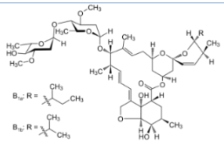
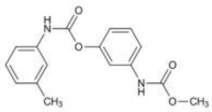
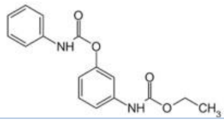
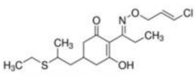
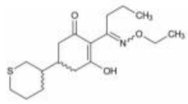
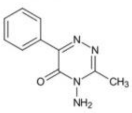
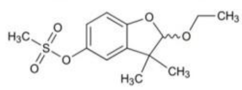
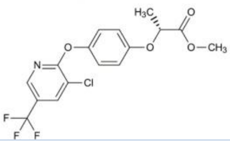
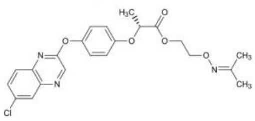
	Sodium channel modulator.		
Cypermethrin			
Organophosphate insecticide		Carbamate insecticide	
	A modulator of sodium channel		Inhibitor of acetylcholinesterase (AChE)
Chlorpyrifos		Methomyl	
Oxadiazine insecticide		Avermectin insecticide	
	A blocker of voltage-dependent sodium channel.		Inhibitor of acetylcholinesterase (AChE)
Indoxacarb		Abamectin	

Table 8. Modes of action of applied herbicides at IPT in the 2020-2021 crop year [20].

Chemical Structure	**Mode of action**	**Chemical Structure**	**Mode of action**
Carbamate herbicides			
	Photosynthesis inhibitor (photosystem II)		Photosynthesis inhibitor (photosystem II).
Phenmedipham		Desmedipham	
Cyclohexanedione herbicides			
	An acetyl CoA carboxylase inhibitor (ACCase).		Fatty acid synthesis Inhibitor. An acetyl CoA carboxylase inhibitor (ACCase).
Clethodim		Cycloxydim	
Triazinone herbicide		Benzofurane herbicide	
	Photosynthesis Inhibitor (photosystem II).		Inhibition of lipid synthesis.
Metamitron		Ethofumesate	
Aryloxyphenoxypropionate herbicides			
	ACCase inhibitor.		ACCase inhibitor.

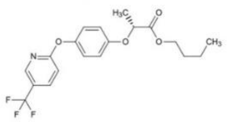
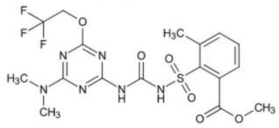
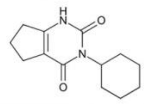
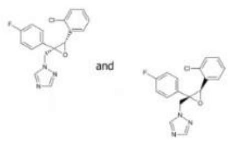
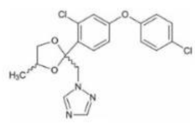
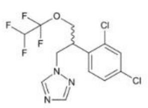
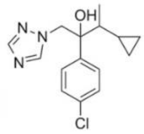
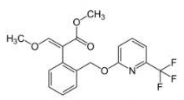
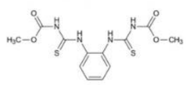
Haloxyfop-P-methyl		Propaquizafop	
	An acetyl CoA carboxylase inhibitor (ACCase).		
Fluazifop-P-butyl			
Sulfonylurea herbicide		Uracil herbicide	
	Amino acid synthesis inhibitor - acetohydroxyacid synthase AHAS		Photosynthesis inhibitor (photosystem II).
Triflusulfuron-methyl		Lenacil	

Table 9. Modes of action of applied fungicides at IPT in the 2020-2021 crop year [20].

Chemical Structure	**Mode of action**	**Chemical Structure**	**Mode of action**
Triazole fungicides			
	Sterol biosynthesis inhibitor		Inhibitor of demethylation during ergosterol synthesis
Epoxiconazole		Difenoconazole	
	Sterol biosynthesis inhibitor		An ergosterol-biosynthesis inhibitor
Tetraconazole		Cyproconazole	
Strobilurin fungicide		Carbamate fungicide	
	Inhibitor of respiration		Inhibitor of cell division and mitosis
Picoxystrobin		Thiophanate-methyl	

Annual quantities used: The tendency to use pesticides is described regarding the amount of each pesticide used in the surveyed area over an entire crop year. Pesticides are widely used because of their total applied amount in surveyed fields (example of Tefluthrin (FORCE 0.5G)); however, other pesticides are widely used because they are compounded in several chemical products (example of Chlorpyrifos (CRATER, LORSBAN, KO, KEMABAN, DURSBAN). To characterize whether the use of pesticide products is done under the recommended doses, a comparison was made between the maximum dose in use per hectare (obtained by survey) and its recommended dose, knowing that the product can be used or not and therefore its minimum dose of use is zero. Also, the number of users of pesticide products is described for each product to identify the most used in the surveyed population.

The tendency of insecticide use varies according to the amount used and user number. Of the eleven insecticides used, chlorpyrifos (organophosphate) is the most used with a total amount of 3530 kg (CRATER, LORSBAN, KO, KEMABAN, DURSBAN) (Fig. 2) and a maximum quantity applied of around 25 kg/ha (Fig. 2). Tefluthrin (FORCE 0.5 G) and bifenthrin (BRIGADA GEO) are also widely used with amounts respectively of 920 Kg and 650 Kg. Cypermethrin (TAIKOK, COLUMBO, CORDUS) is used at 87 kg, with a maximum quantity of 8 kg/Ha. The insecticides with the highest number of users in the surveyed area are indoxacarb (AVAUNT), chlorpyrifos-ethyl (CRATER, LORSBAN, KO, KEMABAN, DURSBAN), and cypermethrin (TAIKOK, COLUMBO, CORDUS).

From the eleven herbicides used, metamitron herbicide is the most widely used herbicide with a quantity of 290 kg per (TWISTER, GOLTIX, MITO) and maximum application of around 2.5 kg/Ha (Fig. 2). The herbicides ethofumesat, phenmedipham, and desmedipham (TWISTER, BISON, BETASANA TRIO, BETANAL EXPERT) are also widely used herbicides with significant total annual quantities and high applied doses per Ha. The herbicides with the highest number of users are phenmedipham, desmedipham, ethofumesate, triflusulfuron-methyl, and lenacil (TWISTER, BISON, BETASANA TRIO, BETANAL EXPERT, SAFARI, VENZAR).

Of the six fungicides used, epoxiconazole is the most used, with a quantity of 55.98 kg (OPUS, BACHLOR, REX DUO) and a maximum application of 2L/ha (Fig. 2). All fungicides used and reported during this survey are used above the recommended dose. The most frequently applied fungicides are epoxiconazole, thiophanate methyl, cyproconazole, and picoxystrobin (OPUS, BACHLOR, REX DUO, ACANTO PLUS).

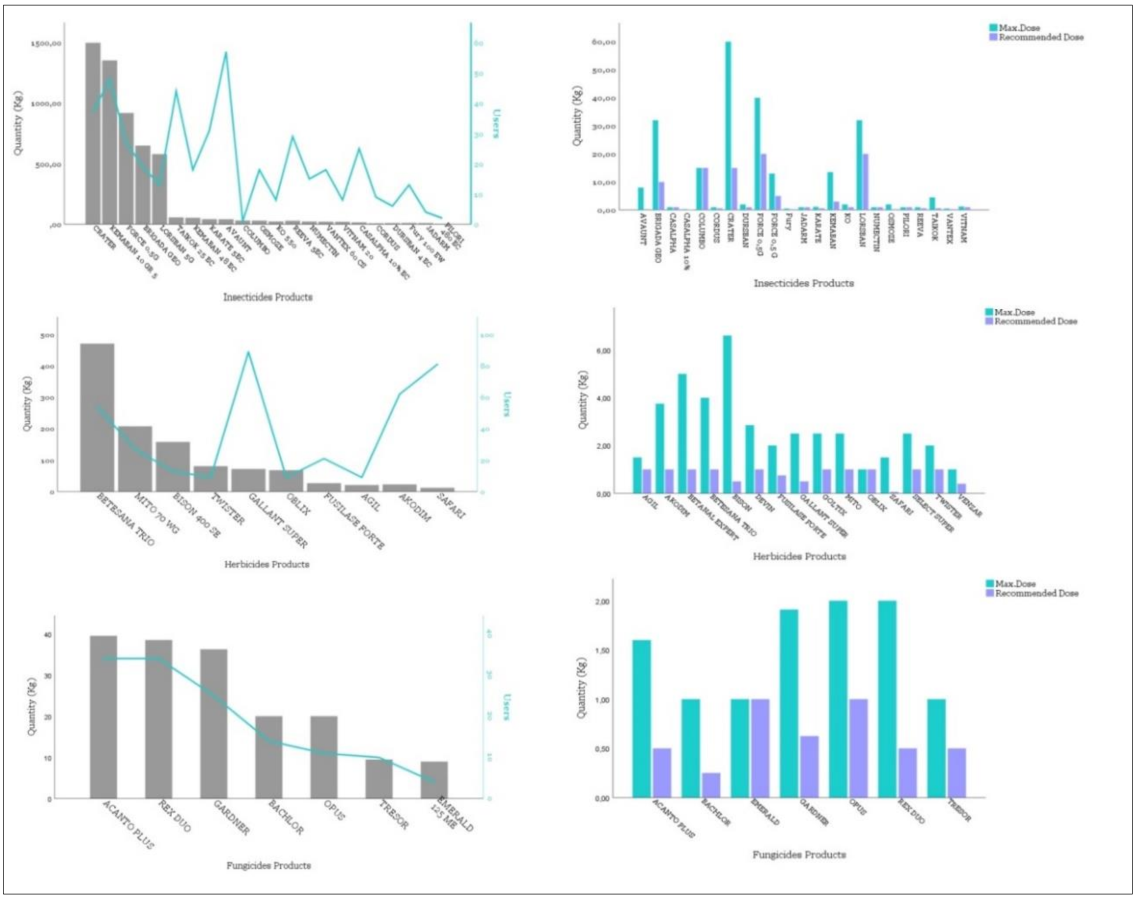


Figure 2. The trend in pesticides used in surveyed sugar areas (left) with the maximum applied pesticides by sugar beet growers compared to their recommended doses (right)

4. Discussion

In order to supply the national and international markets continuously, sugar beet cultivation has been extended in the TPI and 4 other areas in Morocco [11]. Sugar beet growers of the rural municipality of Sidi Jabeur in IPT apply adapted agricultural practices to achieve optimal root yields with high sugar content. Sugar beet yield depends on site conditions (soil types and properties), farm characteristics (field size), and production factors like sowing time and annual conditions, N fertilization, pest, pathogen, and weed pesticide treatment [23,24]. The result from the survey on used agrochemical inputs in 148 sugar beet fields shows a whole agrochemical package, including fertilizers, pesticides, adjuvants, pH regulators, and plant growth promoters used to meet the growth and protection needs of sugar beet crops. 14% of fields use the entire agrochemical package. And 57.63% use a combination of herbicides, insecticides, fungicides, adjuvants, and fertilizers. The rest of the fields use at least one class from the agrochemical package. These results indicate that the conventional cropping system adopted in the surveyed area is based on agrochemical inputs for developing and improving the sugar beet crop over its maturation cycle.

Fertilizers are the most applied agrochemicals, with a total quantity of 192,800 kg. They are applied in 132 fields (89.18%), emphasizing the importance of fertilization for sugar beet crops, as reported in many research works [25–27]. Nevertheless, their use diverges among the fields surveyed. About 10% of sugar beet fields only apply mineral fertilizers, 45.27% only apply nitrogen fertilizers, and 10.81% do not use any fertilizers. In addition, the amount of fertilizer applied/ha does not correspond, in most fields, to the amount recommended by the IPT sugar extraction professionals (Table 2), i.e., approximately 400 Kg for mineral fertilizers and 450 Kg for nitrogen fertilizers). A fertilizer deficit negatively impacts sugar beet growth and causes soil depletion risks, while excessive use is not without consequences for groundwater quality [28]. Nitrate contamination affects groundwater tables in the two sub-perimeters of Tadla (Beni Amir and Beni Moussa); however, it is more accentuated in Beni Amir, which is recognized by intensive citrus agriculture [1]. Therefore, monitoring nitrate content in soil and groundwater underlying sugar beet fields is necessary to infer impacts in groundwater quality and differentiate them from impacts caused by other cultures at the IPT.

Unlike previous years when pesticides were only concerned with sophisticated and extensive plots, pesticides are applied to fields of different sizes in the study area. Pesticides (insecticides, fungicides, and herbicides) are applied in 144 fields, i.e., 97.29% of the total surveyed fields. Insecticides are applied by 96% of fields and correspond to the most used category with 5425.45 kg. They dominate the trend of pesticide use, probably due to pest pressure in IPT and the need to control sugar beet crops [10]. The trend in insecticide use concluded in this study disagrees with pesticide use reported in Saiss perimeter [29] and IPT [30] where herbicides dominated instead of insecticides. All insecticides are approved for control of main enemies in sugar beet fields, such as *Cassida vittata*, *Spodoptera littoralis*, *Pegomya beta*, *Agrotis Sp*., *Conorhynchus mendicus*, *Heterodera schachtii*. They have different registration periods, allowing this crop to benefit from sufficient protection. The most used products are KEMABAN, CRATER (chlorpyrifos), and FORCE 0.5 G (tefluthrin). CRATER (chlorpyrifos) and FORCE 0.5 G (tefluthrin) are buried in granules at sowing as a prophylactic treatment for good seed protection in the period of seed germination [31]. However, despite the importance of insecticides for pest control, their use pattern varies between the surveyed sugar beet farms. It is sometimes marked by overuse and underuse in the sugar beet fields. Each commercial insecticide product has a small number of users among the population surveyed. The small number of users associated with a high quantity of certain pesticide products indicates excessive use, but only by a minority of fields.

Weed control is vital in sugar beet management [32]. Tillage, weeding, and alternating crop rotation are effective operations for weed control [32,33]. The inventory of different operations used in weed management in sugar beet fields does not fall within the objectives of this research; however, chemical control by herbicides remains an option frequently used for weed control in investigated fields in IPT. 92% of fields use herbicides, anti-grasses, and broadleaf weeds, i.e., 1508.41 kg, due to the speed of weeding execution by herbicides, the possibility of intervention in rough terrain, and the high cost associated with labor in IPT. Herbicides in use have a registration period from one to 9 years, allowing this crop to benefit from sufficient herbicide products to prevent weed resistance. Composed of 7 families, the herbicides triazinones (metamitron) and carbamates (desmedipham, phenmedipham) were the most dominant families of herbicides in quantity used. All herbicides were used above the recommended dose in at least one sugar beet field, probably due to late control after the widespread weed infestation.

Fungicides are essential to crop protection and continue to play a crucial role in managing devastating sugar beet diseases [34]. Their use in sugar beet crops has gained importance in controlling most harmful diseases like *Cercospora beticola* [34]. 172.75 kg of registered fungicides are used in the sugar beet surveyed field. Given their registration period, which ranges from 2 to 4 years, there is a need to introduce new fungicides to allow sufficient control of sugar beet diseases. The fungicides used belong to 4 families, including triazoles (epoxiconazole, cycloconazole, difenoconazole, tetraconzale), which are dominant in quantity used. The most used products in terms of quantity and users are ACANTO PLUS and REX DUO, which are used in treating Mildew, and cercosporiosis. All of the fungicides reported in the survey are exceeding recommended doses at least at one sugar beet field. Nevertheless, their number of users remains low. This is probably due to the control of fungal diseases mainly through seeds-resistant varieties, which provide adequate protection with a reduction of fungicide use [35].

Chemical control is crucial in reducing losses associated with pathogens, pest attacks, and weed infestation [10,23,24]. Optimized use of these agrochemicals has not affected agricultural yield [36]. Many studies conclude that the benefits of pesticides far outweigh their harms if they are used safely and within recommended limits [8]. The harms of pesticides are mainly related to their toxicity on the field workers, consumers, and the ecosystem [37]. Overusing pesticides can cause soil and groundwater contaminants [38]. Pesticide residue concentration in soil or plants can sometimes be well above the acceptable limit, and this varies with the nature of the pesticide used, soil, climate, applied quantity, and frequency of use [38]. Triazole fungicides are used for foliar sprays on cereals, vegetables, and vineyards or as seed treatment [39]. Triazole fungicides are toxic to various soil microorganisms, including bacteria and fungi [40,41]. The presence of pesticide residues in groundwater has been reported by monitoring studies in intensive agricultural areas [38,42]. Ethofumesat is banned from sugar beet farming in Germany following its detection at numerous wells [43]. Research has revealed the presence of chlorpyrifos in streams and groundwater in many agricultural regions [38]. In the IPT, given the expansion of sugar beet crops associated with the significant use of pesticides highlighted in this study, it is necessary to monitor pesticide residues in groundwater to infer their fate and prevent rural population exposure to wells-contaminated water and related health hazards.

Taking into account the long history of the establishment of the sugar beet crop and its distribution within the perimeter and given its vulnerability to pests, pathogens, and weeds, and the chemical control they require, the impact of pesticides used in the sugar beet crop can be problematic in the surveyed area and for IPT in general. However, a significant limitation of this study is that it only addresses the amount of pesticide applied as a quantitative aspect of risk by comparing the actual application rate and the recommended dose of each pesticide. To consider the risks associated with these pesticides on the IPT agroecosystem, we need to consider the effects of toxicity and the quantity of pesticides applied.

5. Conclusion

The sugar beet crop is vulnerable to a host of enemies. According to the results of this survey conducted during the 2020-2021 agricultural campaign, fertilizers are being used irrationally. Controlling weeds, pests, and pathogens to achieve optimum yields relies mainly on chemical control. Insecticides are used more by beet growers, attesting to the importance of controlling sugar beet pests. Herbicides are also abundantly used to control weeds. Fungicides are the least used pesticides, probably due to the use of varieties resistant to certain harmful diseases. However, the use of pesticides revealed by the survey results remains uneven among the beet growers surveyed at the PIT. Therefore, training farmers on the rational use of pesticides would be fascinating. Also, developing management plans for weeds, pests, and diseases using phytosanitary products must be based on minimizing risks from these products to minimize their effects on humans and the environment.

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