Effect of Resource-Saving Technologies of Arable Land Cultivation on Diabetes Mellitus Incidence (A Case Study of the Republic of Tatarstan)

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Abstract

The activation of the use of resource-saving soil cultivation technologies, accompanied by increased use of glyphosates, needs a medical and environmental assessment. A retrospective cross-sectional study included data from official sources of the Republic of Tatarstan for 2002-2016. An analysis of the dynamics of trends, multiple correlation-regression and variance analysis was carried out using AtteStat and PSPP software. Since 2002 in the republic the areas treated with new technologies increased, with the area growing (R^2=0.13), the amount of pesticides used (R^2=0.27), herbicides (R^2=0.13) and glyphosates (R^2=0.78). Between the fields reduced-till and no till and glyphosate a strong correlation was found to be very significant: r=0.93 (95% CI: 0.81-0.98; p<0.0001) and r=0.92 (95 % CI: 0.77 ÷ 0.97, p<0.0001) respectively. For 15 years the share of the population with diabetes in the republic has increased from 1.3% to 3.23% with the highest growth rate in the adult population of the prevalence of type 2 diabetes (257.5%), whose share by 2016 has reached 3.8%. Significant dependencies of the treatment area, the consumption of pesticides and herbicides with the prevalence of diabetes mellitus in the adult population were absent, whereas with incidence of diabetes mellitus in the second or third year. The degree and significance of the connection between the volume of glyphosates, area of field with the reduced-till and no till technology, and the prevalence of diabetes mellitus was more than that of incidence. In conditions of using resource-saving technologies, the model of prevalence of CD2 in the adult population of the republic was determined informative, adequate and stable at the most statistically significant role of glyphosates (R2=0.98, p<0.003) among other pesticide indices. Further expansion of the use of new technologies and glyphosate-containing preparations requires monitoring and analysis not only of agricultural specialists, but also of environmental medicine.

Keywords: Reduced-Till and No Till Technology, Herbicides Glyphosate, Diabetes Mellitus.

Introduction

The aim of our study was analysis of using resource-saving technologies of arable land cultivation and pesticides with assessment of relationships and contribution of certain parameters to incidence rates of diabetes mellitus on a scale of territorial entity of the Russian Federation with a developed agricultural sector.

Methods

Ecological study was carried out based on the materials of the Republican Medical Information-Analysis Centre of the Ministry of Health of the Republic of Tatarstan (the RT) including an annual study guide “Population health and healthcare statistics (a case study of the Republic of Tatarstan)” for the period of 2000-2016, the Ministry of Ecology and Natural Resources of the RT and the branch of FSBI “Russian Agricultural Center in the RT”. Analysis of the events dynamics with calculation of the coefficient of determination of the trend approximation was performed. Growth rates of primary disease incidence and prevalence of DM, DM1 and DM2 in children aged 0-14 years old, 15-17 years old and adults (18 years and older) were calculated. The normality of variation series distribution was checked by means of Shapiro-Wilk test. An achieved significance level was calculated at all stages of statistical analysis, 0.05 being taken for its critical level. To determine connections between indices, a non-parametric coefficient of Spearman rank correlation with indication of 95% confidence interval (CI) was calculated year in and year out, and with a lag (lag time) of 1-2 years. The methods of multidimensional statistics (multiple correlation-and-regression analysis with subsequent application of dispersion analysis) were used to assess the relationships and contribution of agricultural

parameters to DM2 incidence rates in the adult population with application of AtteStat [3] and PSPP software.

Results

The RT ranks third in agricultural output in RF. In the year 2016, 68.8% of 6783.7 thous. ha of the area were agricultural lands including 3362.6 thous. ha of arable land (49.6% of the entire territory of the Republic). More than 52% of croplands are occupied by cereal crops, 37% − forage crops, 7% − industrial crops, and 3% − vegetables.

In 1999, the use of chemical pesticides in the Republic reached their lowest values since 1985: in the cultivated area, the gross consumption and the territory load. In the years that followed, the parameters were growing and became the highest in area in the year of 2008 (3899 thous. ha), in volume - in 2015 (2310.8 tons) with annual variation of the territory load from 0.21 to 0.78 kg/ha. However, the growth of the area and volume of the pesticides' use was defined as unstable in the value of the coefficient of determination of the trendline approximation (R^2=0.13 and R^2=0.27 correspondingly), as well as the volumes of herbicides (R^2=0.13). The proportion of the latter among pesticides varied during the period of 2002-2016 from 50.9% to 76.7%.

Implementation of resource-saving technologies started in the Republic since the year of 2002. The land use area cultivated according to reduced- and no-till technologies for the period of 15 years increased according to Chaddock's scale to a high (2.2 times) and extremely high (21.5 times) degree correspondingly in case of clear sustainability (Fig.1).

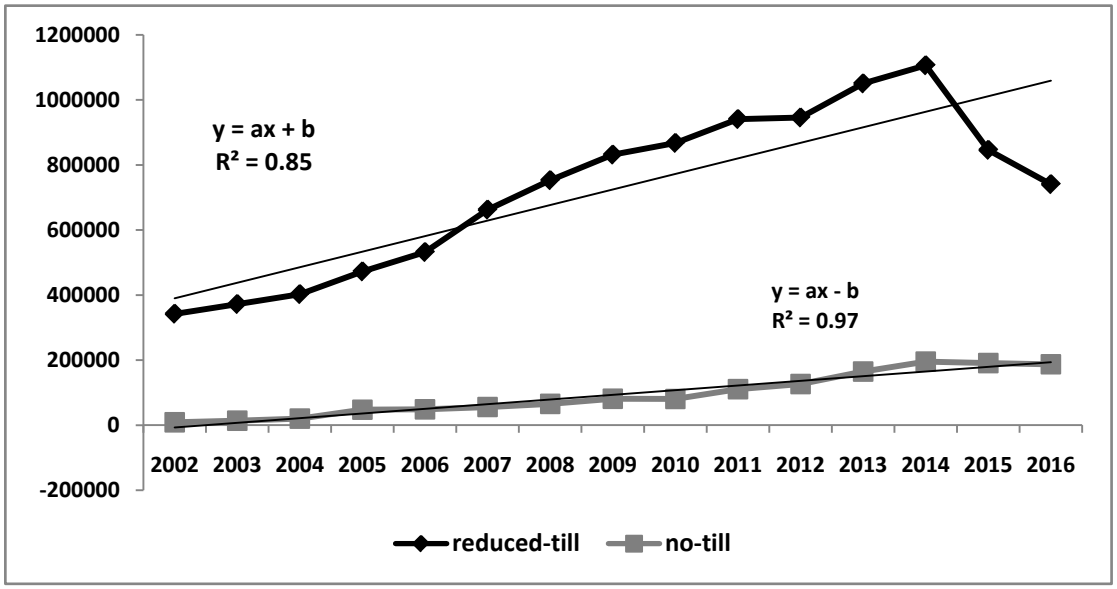

Fig.1: Dynamics of the arable land area cultivated according to reduced- and no-till technology in the Republic of Tatarstan indicating the coefficient of determination of the trendline approximation, in hectares

If in 2002 they were used on 10.1% of the entire area of arable land in the Republic, then on annual extension by the year of 2014 – on 39.7%, having decreased to 27.6% in 2 subsequent years. During these years, reduced tillage was carried out on the major part of the indicated area (97.5% in 2002, and 79.8% in 2016).

Implementation of new technologies was accompanied by the increase in consumption of preparations to fight against perennial weeds, and the domination of glyphosate-based preparations (glyphos, glyphor, glyder, glyphogold, roundup, tornado, argument, fakel). The spectrum of pesticides changed considerably in active ingredient and the number of trademarks during 15 years. The proportion of 2.4-D derivatives decreased to 9.8% among herbicides. The use of preparations of phenoxaprop-P-ethyl (up to 19% of all herbicides), desmedipham and phenmedipham (up to 18%), and dicamba became more frequent. The volumes of glyphosates' use reached the highest values in 2011: 347.5 thousand tons (34.2% of all herbicides and 19.3% of pesticides on the whole). Despite annual fluctuations, the consumption increase was high (R^2=0.78).

In the period of 1991-2003, the growth rate of primary DM incidence among the whole population made 51%; prevalence – 29.4%. In the period of 2004-2016, during a slight decline of the growth rates of the frequency of new DM cases the takeoff of the prevalence growth rates by a factor of 3.9, first of all, in the adult population and children aged 15-17 years old took place (Tab.1). In 1991, the proportion of population with diagnosed DM in the RT made 1.07%; in 2003 – 1.3%; and in 2016 – 3.23%.

Table-1: The growth rate of diabetes mellitus incidence among various population groups of the RT (the years 2004-2016), %

Group	Primary incidence			Prevalence		
	DM	DM1	DM2	DM	DM1	DM2
The whole population	43.5	5.2	47.3	115.7	26.4	126.8
Children aged 0-14 years	41.9	40.7	935.0	67.9	68.5	32.7
Children aged 15-17 years	117.9	104.2	526.0	118.6	124.6	-21.0
Adults aged 18 years and older	40.4	-9.0	121.9	111.7	20.2	257.5

High degree and steady growth pattern of DM prevalence in the adult and child population aged 15-17 years old are confirmed by the values of the coefficient of determination of the trendline approximation: 0.99 and 0.82 correspondingly. In children aged 0-14 years old, it was lower – 0.62.

In 2016, taking into account the age composition of the population in the Republic (the adult population makes 79.9%), the overwhelming majority of diabetic patients were 18 years of age and older: 124 005 persons (99.1% of all DM cases among the whole population), 64.4% of them being older than working age (females older than 55 years; males – older than 60 years).

According to the world statistics, in the years 2004-2016, DM2 prevailed among the adult population, the proportion of which in DM varied in the range of 90-96.7% at high growth rates of the frequency of new cases and prevalence. A positive significant relationship (r=0.73 at 95% of CI: 0.07÷0.95 and p<0.002), which is missing between the frequency of new cases of indicated nosologies, was identified between the prevalence of DM2 and DM1 in the adult population. DM 2 was revealed in 3.8% of the adult population and 62% of them were persons older than working age.

In the child population, 95.9÷99.7% of diabetes were represented by DM1, the growth rate of its prevalence corresponding to 68.5% in the age category of 0-14 years old and 124.6% − among 15-17-year olds. Very high growth rates of primary DM2 incidence among children of both groups are explained by the small absolute number of newly diagnosed cases: 0-3 cases a year, and this in terms of relative indices (per 100 thous. children) means that each case exceeds manifold the values of the previous years.

The results of carried out analysis show that in the Republic the most negative in the growth rates and the proportion of the population with diagnosis of DM2 (3.02%) is the dynamics of its prevalence, in the adult population, in particular. The relationship between the prevalence of DM2 and obesity: r=0.92 (95% of CI: 0.76÷0.98; p<0.0001) was identified among the adults confirming the parallelism of the epidemic growth of diabetes and obesity and the notion of “diabesity” (**dia**betes-o**besity**) itself.

There were no statistically significant relationships between the pesticide-treated area, the pesticide consumption on the whole and herbicides, and prevalence of DM2 among the adult population of the Republic, whereas they were evident as to the frequency of new cases only in the second or the third year, that is, the lag of the enumerated factors’ aftereffect in time was observed (Tab.2). The strength and significance of correlation between the glyphosates’ volume, the reduced- and no-till area with the total incidence of DM2 were significantly higher compared with the primary one.

Table-2: The value of the correlation coefficient with 95% confidence interval of DM2 incidence among the adult population of the RT with parameters of using pesticides and tillage resource-saving technologies (the years 2002-2016)

Factor	Primary incidence	Prevalence
Pesticide-treated area, in hectares	With a lag of 1year 0.66: 0.18÷0.89; p<0.01	-
Pesticide consumption, in tons	With a lag of 2 years 0.58: 0.05÷0.86; p<0.02	-
Herbicide consumption, in tons	With a lag of 2 years 0.75: 0.34÷0.92; p<0.001	-
Glyphosateconsumption, intons	0.59: 0.06÷0.86; p<0.02	0.85:0.55÷095; p<0.0001
Reduced-till area, in hectares	0.59:0.05÷0.86; p<0.02	0.72: 0.28÷0.91; p<0.003
No-till area, in hectares	0.84:0.53÷0.95; p<0.0001	0.97: 0.91÷0.99; p=0

Determination of a fact of the impact precedence to anticipated outcome in the form of the adverse effect incidence and assessment of the statistical relationship strength is considered to be insufficient, although under specific conditions it is acknowledged to be a proof of health deterioration causes.

Highly significant strong correlation: r=0.93 (95% of CI: 0.81÷0.98; p<0.0001) and r=0.92 (95% of CI: 0.77÷0.97; p<0.0001) correspondingly was revealed between the area cultivated according to reduced- and no-till technologies and the application volume of glyphosate-containing preparations. Therefore the latter were excluded at the next stage of the study of relationships between the incidence of DM2 among the adult population and the parameters of pesticides' use and the soil processing technologies.

Multilevel regression analysis determined that primary incidence of insulin-independent diabetes mellitus among persons of 18 years of age and older is statistically significantly associated neither with the tilled area and the volume of pesticides, herbicides and glyphosates on the whole, nor with each of the enumerated indices. The model describing relationships of the total DM2 incidence with indicated parameters of arable farming was identified as informative (in the value of multiple correlation coefficient 0.96, and multiple coefficient of determination equal to 0.93, correspondingly), adequate (according to the value of Fisher's test =16.5 at p=0.0098) and stable (according to results of the correlation matrix analysis). The highest relationship of three predictors of DM2 was in the volume of glyphosate-containing preparations, and the power of their influence on the prevalence of DM2 among the adult population appeared to be not only rather high, but highly significant as well: the nonstandardized coefficient of determination corresponded to 0.86; and the standardized one – 0.98; p<0.003.

Discussion of Results

Arable land occupies half of the territory of the Republic, and in combination with high population density (on the average 57.4 persons/km^2, and in the regions - up to 85-90 persons/km^2) determines the weight of the processes taking place in this sector. In Russia, the pesticide prices grow less markedly than for equipment, fuel material and mineral fertilizers and even decrease − since the year of 2005 glyphosates fell in price by 45%. The use of herbicides in combination with new technologies in crop farming becomes cost-effective [8, 28]. Consequently, the trends indicated in this work will continue in the regions in the immediate future, and oversupply in the market of glyphosates and appearance of new enterprises for their production will contribute to it. The trend pattern of the areas cultivated according to reduced- and no-till technologies in particular, and glyphosates' consumption in the RT say for this prognosis.

At the same time, the risk of glyphosate transport in case of surface tillage with windblown precipitation particles and dust beyond the agricultural regions, where it is used, to non-targeted regions is assessed as very high. Glyphosate, particularly in the form of salts, is a sufficiently stable chemical compound, and its fixation with soil particles due to availability of phosphonic acid, carboxyl and amino groups in the structure is responsible for accumulation in other environmental compartments. The highest content of the compound and the product of its transformation – aminomethylphosphonic acid (AMPA) was revealed in soil fractions with diameter of PM10 and less, which penetrates deep into the human body tissues and cells [10]. Glyphosate, which dominated in total herbicidal flow and AMPA, was found in ≥75% of the air and rain samples taken from the sites at 3m and 500 m from active fields [15]. In case of extensive application in conditions of reduced- and no-tillage, from 0.01 to 9.1mg/m^3 of glyphosate and AMPA were revealed in the atmospheric air, which at present are among the major pollutants of the water bodies in a number of countries [11, 13, 18, 29].

Taking into consideration the high interrelationship between the consumption of glyphosates and resource-saving technologies, revealed in our study, and literature data, not only glyphosate in itself, but possibility of its distribution in case of surface tillage act as a negative factor. The increasing volumes and new fields of its use (just before harvesting) increase risks for the environment and a human being. Exposure of the population to glyphosate and the product of its transformation increases. At the same time, in spite of the growth of a number of papers on the effects of this preparation and its formulators in recent years, there is not enough valid evidence of toxic effect of glyphosate in concentrations really present in the environment, on certain human body organs and systems. The contribution of different routes and sources of glyphosate's getting into the body is still not clear, and it is assumed that up to 95% of pesticides in non-production conditions are ingested with foods and water.

In 2001, glyphosate and aminomethylphosphonic acid (AMPA) were found in cryoarchived urine samples of the residents of these territories in 10.0% of cases; in 2012-2015 already in 32.5-57.5%, this fact being regarded as the capacity of these compounds for material cumulation [12]. Glyphosate was found in urine and breast milk in 99.6% of examined persons, having no direct contact with herbicide [5]. The fact that the significance value and the degree of its impact on prevalence of DM2 in the adult population were significantly higher than similar parameters as for the frequency of new cases can also serve an indirect evidence of the preparation cumulation in the human body. Our findings coincide and deepen the results of epidemiological analysis of

the materials of the period 1960-2010, which revealed a strong correlation between the volumes of glyphosates' use in the corn and soybean fields and prevalence of DM (r=0.96) [17, 27]. Absence of regular sampling of glyphosate in various environmental compartments because of legal and methodological limitations in many countries including Russia, does not allow applying a riskometer approach and classical epidemiological analysis of concentrations in the environmental compartments and biomaterials. Therefore the carried out assessment of the changes taking place in arable farming is justified in total indices.

There is another cause of the fact that much of what is known about glyphosate-containing preparations and compounds having toxic effect on the endocrine system, should be studied, investigated and examined by means of unconventional methods. The scientific community places emphasis on the fact that the effects of "the endocrine disruptors" are characterized by nonmonotonicity, and a classical toxicological principle that "the dose makes the poison" is not always plausible in regard to them. They can occur in extremely low concentrations (nano-micromolar and picomolar range), reflecting compensation-reduction procedures of the homeostatic maintenance in response to damaging effect [20-26]. Consequently, fixation only on the observance of "safe" levels of glyphosate and its metabolite in certain environments based on the results of episodico and/or regular control by supervisory services can result in underestimation of real consequences for the endocrine health of the residents of the territories, where they are used.

The obtained results imply the importance of epidemiological tracking of implemented new technologies in the agricultural sector for decreasing the deterioration of the population health and the development of methodology for risk assessment.

Conclusions

Glyphosate herbicides make a considerable contribution to the increase of type 2 diabetes mellitus prevalence among the adult population of the region, when using reduced- and no-till technologies of arable land cultivation.

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