The effect of perennial forage crop on grain yields in submontane regions

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ABSTRACT

The structure of crop production (areas under crops, crop yields, fertilization) in 15 agricultural farms in potato-production and mountain regions of the Czech Republic was analyzed to evaluate the relations between NPK fertilization level, percentage of perennial forage crops on arable land and grain yields as the basic indicator of crop production output. A multifactor analysis based on simple regression equations indicated direct relations between the two above-mentioned factors and yield. Correlation and regression analyses demonstrated a close correlation between grain yields and percentage of perennial forage crops on arable land especially when lower nutrient rates in fertilizers were used (below 100 kg NPK.ha^{-1} arable land). This relation was expressed for the whole set of initial data by the equation: Grain yield t.ha^{-1} = log^2 (NPK rate in kg.ha^{-1} arable land + X% of perennial forage crops). The coefficient of perennial forage crop effect (X) in the range of 0–1.47 can be explained by soil enrichment with nitrogen, mobilization of other nutrients, improvement of soil structure and reduction in the weed infestation of soil. The effect of perennial forage crops on grain yield increase was quantified (estimated) from the whole set of data using the above equation at X = 0 by the value +0.42 t.ha^{-1}. The yield increase per 1 kg NPK.ha^{-1}of arable land amounts to 0.0501 t.ha^{-1}, i.e. every 1% of forage crops on arable land increases the grain yield by 0.023 t.ha^{-1} within the set. The relation between actual and theoretical yield of the whole set is demonstrated by correlation coefficient (r = 0.9332) if the effect of perennial forage crops is estimated by coefficient X = 0.95, if the effect is estimated by coefficient X = 1.47, the correlation coefficient is even higher (r = 0.9977).

Keywords: marginal regions; grain yields; NPK fertilization; percentage of perennial forage crops

The strategy of sustainable development of agriculture in the CR envisages intensive management in so called production regions and production of marginal industrial crops including the expansion of grasslands in so called marginal regions. These areas for other use in the CR account for 465 000 ha of arable land and 523 000 ha of meadows and pastures. Cattle production is the best use of grasslands. According to Kvapilík (1999) the production potential in the CR can be 200 000–230 000 cows without milk production and relevant stock of young animals. Statistical data indicate that the actual stock in 2001 is 98 000 head. Vrkoč and Vach (1995) stated that the structure of crop production in submontane areas would undergo more consistent differentiation of the cropping pattern in relation to agroecological and economic conditions of the localities. These authors were convinced that in marginal (submontane and mountain) regions it was necessary to revise the level of grain production, particularly rye and oat production, because their areas largely decreased.

Particular crops grown on arable land at these locations can be produced under systems of different farming intensity (Petr et al. 1980). Perennial grass and clover-grass swards with lower inputs reflect a certain level of extensity in final production. On the other hand, grain crops, root crops and industrial crops require direct costs. Vrkoč and Vach (1995) reported that based on economic calculations the costs of the same yield of grain crops and other crops in marginal conditions were higher by 1000–2000 Kč per hectare than in lowlands if higher rates of especially nitrogenous fertilizers were used. Similar conclusions were drawn by Šroller and Šimon (2000).

A question arises in this context to what extent the grain yield and grain yield stability are influenced by another intensification factor – forecrop, i.e. perennial forage crop. We asked this question when analyzing the yields from 15 farms in submontane regions.

MATERIAL AND METHODS

The complete analysis of 15 agricultural enterprises was focused on production indicators of crop and animal production including costs. The objective of the paper was to determine what factors influence the level of crop production expressed by grain yield and to what extent. The agricultural enterprises are situated in potato production and mountain regions at an altitude of 650 m above sea level, climatic region B, and climatic subregion 7–9. Average annual temperatures range from 6.95 to 7.6°C, annual precipitation sums are 627–771 mm. Soils are mostly loamy or sand-loamy, the most frequent soil types are Cambisols or stagno-gleyic Cambisols and luvic Cambisols. The load of livestock unit per 1 hectare of farmland ranges from 0.25 to 0.63.

Grain yields reflecting the level of cultural practices and yield potential of the locality in an appropriate way were taken as the basic indicator of crop production level. Among the factors, influencing yield (cultural practices, variety, fertilization, protection measures) the effect of NPK fertilization per 1 hectare of arable land and percentage of perennial forage crops (clovers and clover-grass mixtures) could be objectively investigated.

A system of regression equations ($x = a + by$) was used to study the relations between grain yields and NPK rates per 1 hectare of arable land. This mathematical solution was also applied to quantify the effect of another factor – percentage of perennial forage crops on arable land.

For statistical data processing such procedures of correlation and regression analyses were used that would express the effect of both independent variables by one equation the most consistent with the reality of the whole set.

RESULTS AND DISCUSSION

Graphical and numerical analyses indicated that grain yields in the studied set of farms were influenced by the percentage of perennial forage crops on arable land to some extent positively. The relation between NPK rate in $kg.ha^{-1}$ of arable land (only NPK hereinafter) and grain yield in $t.ha^{-1}$ (only Yield hereinafter) had the form of quadratic logarithm: yield = $\log^2$ (NPK). This simple relation assumed the value of correlation coefficient 0.8791 for the whole set, confirming a definite effect of fertilization level as well as the effect of another factor. Further investigations into a potential closer correlation between calculated and actual yield were aimed to establish the correlation between the effect of fertilization (NPK) and the area of perennial forage crops on arable land as an important forecrop of grains (only P% hereinafter).

The solution of these two simple relations – equations resulted in the following equation to calculate the effect of NPK fertilization and perennial forage crop percentage on grain yield: (actual) yield = $\log^2$ (NPK + X%).

The calculation of X from the actual yield indicates the effect of perennial forage crop percentage on grain yield, the term in brackets showing the sum of the effect of both factors.

The effect of perennial forage crops on grain yield was calculated from the above equation. Every 1% of forage crops on arable land increases grain yield by 0.023 $t.ha^{-1}$ in the investigated set of farms, grain yield increase per 1 kg NPK amounts to 0.0501 $t.ha^{-1}$.

By a more detailed investigation the solution of the equation resulted in a low (minimum to negative) effect of perennial forage crops (value X) in the group of farms on which NPK rates higher than 100 kg per ha of arable land were applied. On the other hand, the value of this coefficient was mostly positive for farms using lower NPK rates. In the former case, the effect of fertilization is dominant if higher NPK rates are applied, in the latter case there is a definite, defined effect of the percentage of perennial forage crops (clovers and clover-grass mixtures) on grain yields at lower fertilization levels in submontane regions. It is illustrated by coefficients X calculated through weighted mean for the group of farms A-C5 where $X1$ = –0.024 (rounded to 0–), $X2$ = 1.469 (rounded up to 1.47) (Table 1).

The coefficient $X = 0.95$ was calculated through weighted mean for the whole set of farms. Using these values (X, $X1$, $X2$) theoretical yields were calculated for every actual yield (Table 2). Figure 1 shows a comparison of actual yield with theoretical yield if the coefficient $X1 = 0.95$ was used – i.e. for the whole set of data, Figure 2 shows a comparison of actual yield with theoretical yield for the coefficient $X = 0$ for the group of farms with fertilization rates above 100 $kg.ha^{-1}$ and for the coefficient $X2 = 1.47$ for farms with rates below 100 $kg.ha^{-1}$ NPK.

Regression equations were calculated from the initial values.

A) The correlation (Table 2) between actual and theoretical yield if the effect of perennial forage crops is estimated by the coefficient 0.95 for the whole set.

$y = 1.5967 \ln(X) - 3.3128$

$R^2 = 0.9948$

Correlation coefficient $r = 0.9332$

Table 1. Basic data on farms and calculated coefficients of the effect of perennial forage crops

Farm Year	NPK ($kg.ha^{-1}$)	Forage crop (%)	(Actual) grain yield ($t.ha^{-1}$)	X for individual yields
A	180	25.00	5.51	1.700
B	150	8.59	4.92	1.773
C1	142	24.00	4.50	–0.407
C2	141	16.69	4.20	–1.734
C3	139	23.67	4.16	–1.244
C4	132	14.70	4.23	–1.228
D	120	5.36	4.07	–2.967
E	116	16.67	4.74	2.061
F	109	8.46	3.99	–1.131
C5	106	15.68	4.15	0.186
G1	99	5.37	4.07	0.948
G2	98	9.32	4.41	2.990
H1	88.4	18.48	4.35	1.807
H2	86.0	20.51	4.84	3.530
H3	85.0	18.00	4.01	0.865
H4	82.0	19.20	4.14	1.370
H5	73.7	18.49	4.32	2.493
CH1	70.0	13.44	3.55	0.489
CH2	60.0	10.30	3.46	1.209
I1	53.0	24.50	3.70	1.259
I2	50.0	23.10	3.60	1.253
J1	50.5	14.08	3.40	1.371
J2	40.0	14.28	3.00	0.977
K	25.0	40.84	3.09	0.806
M	25.0	0.00	2.10	3.127
N	19.9	17.60	2.50	1.032
O1	13.2	14.81	2.50	1.682
O2	12.0	16.20	2.30	1.284

B) The correlation (Table 2) between actual and theoretical yield if the calculation of the effect does not include the effect of perennial forage crops on arable land ($X = 0$) for NPK rates above 100 kg.ha^{-1}, and for rates below 100 kg.ha^{-1} the effect of perennial forage crops is included using a higher coefficient ($X2 = 1.47$), that means the weighted mean of a part of the set.

$y = 1.6143 \ln (X) - 3.411$

$R^2 = 0.9955$

Correlation coefficient $r = 0.9977$

A close relation between the effects of both factors was confirmed by the above correlations.

The equations also enabled to quantify the effect of perennial forage crop percentage on arable land on average grain yield by using $X = 0$ for the whole set of data. This calculated share of the effect of perennial forage crops accounts for a grain yield increase +0.42 t.ha^{-1} as a difference between actual yield and theoretical yield not including the forage crop percentage ($X = 0$). If the effect of forage crops is included in the equation for the calculation of average theoretical yield of the whole set, the difference between actual and theoretical grain yield ($X = 0.95$) is only 0.01 t.ha^{-1}, which confirms the correctness of the hypothesis within the evaluated set along with the values of regression equations and correlations.

Grain yields, similarly like yields of other crops, are influenced by a number of factors – soil, forecrop, variety, fertilization, cultural practices, protection, weather conditions, etc. (Petr et al. 1980). Kudrna (1979) emphasized the importance of perennial forage crop percentage in relation to yield stability in the whole farming system. It has also been confirmed by recent findings; Vaněk et al. (1999) demonstrated a higher yield increase when full fertilization rates were applied in a potato production region while favorable effects of clover crops were taken into account. Kubát et al. (1999) studied the importance of nitrogen cycle and demonstrated that nitrogen could not be accumulated in the soil the long run than in soil organic matter. The effect of perennial forage crops on the nutrient status of soil was also reported by Štorkanová et al. (1999) who studied some *Rhizobium* strains that intensively solubilized mineral compounds of phosphorus. The important role of perennial forage crops on arable land for grain yield stability in submontane regions

Table 2. Comparison of actual and theoretical (calculated) yields

Farm Year	Actual grain yield (t.ha^{-1})	Average of $X = 0.95$	Sum of effect	Theoretical grain yield (t.ha^{-1})	$X = 0$ $X = 1.47$	Sum of effect	Theoretical grain yield (t.ha^{-1})
A	5.51	0.95	203.7	5.33	0	180.0	5.08
B	4.92	0.95	158.1	4.83	0	150.0	4.73
C1	4.50	0.95	164.8	4.91	0	142.0	4.63
C2	4.20	0.95	156.8	4.82	0	141.0	4.61
C3	4.16	0.95	161.5	4.87	0	139.0	4.59
C4	4.23	0.95	145.9	4.68	0	132.0	4.49
D	4.07	0.95	125.1	4.40	0	120.0	4.32
E	4.74	0.95	131.8	4.49	0	116.0	4.26
F	3.99	0.95	117.0	4.28	0	109.0	4.15
C5	4.15	0.95	120.9	4.33	0	106.0	4.10
G1	4.07	0.95	104.1	4.07	1.47	106.9	4.11
G2	4.41	0.95	106.8	4.11	1.47	111.7	4.19
H1	4.35	0.95	105.9	4.10	1.47	115.5	4.25
H2	4.84	0.95	105.5	4.09	1.47	116.1	4.26
H3	4.01	0.95	102.1	4.03	1.47	111.4	4.19
H4	4.14	0.95	100.2	4.00	1.47	110.2	4.17
H5	4.32	0.95	91.2	3.84	1.47	100.9	4.01
CH1	3.55	0.95	82.7	3.67	1.47	89.7	3.81
CH2	3.46	0.95	69.8	3.40	1.47	75.1	3.51
I1	3.70	0.95	76.3	3.54	1.47	89.0	3.80
I2	3.60	0.95	71.9	3.45	1.47	83.9	3.70
J1	3.40	0.95	63.9	3.26	1.47	71.2	3.43
J2	3.00	0.95	53.5	2.98	1.47	61.0	3.18
K	3.09	0.95	63.8	3.25	1.47	85.0	3.72
M	2.10	0.95	25.0	1.95	1.47	25.0	1.95
N	2.50	0.95	36.6	2.44	1.47	45.8	2.75
O1	2.50	0.95	27.2	2.06	1.47	35.0	2.38
O2	2.10	0.95	27.4	2.06	1.47	38.8	2.41

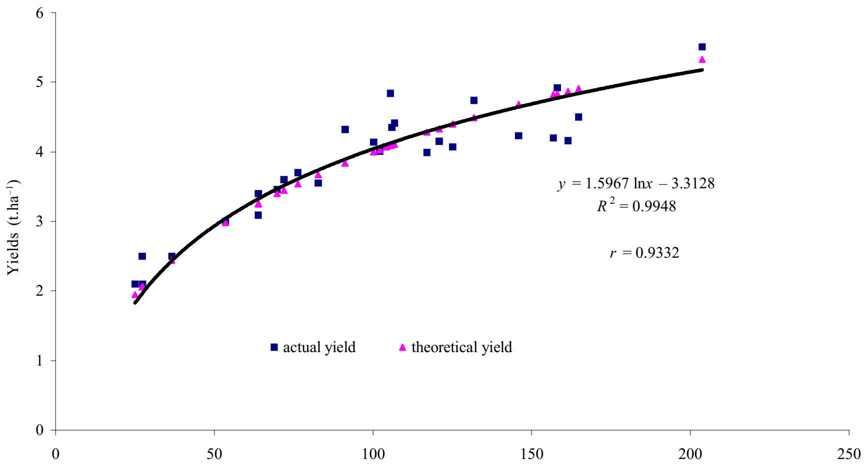

Figure 1. The effect of fertilization and perennial forage crop percentage on grain yield (the effect of forage crops 0.95); the sum of fertilization (kg NPK.ha^{-1}) + 0.95 × percentage of perennial forage crops on AL (%)

was confirmed by Vrkoč and Vach (1995) as well as by Křen (1996). There arises a question to ask: to what extent do the calculated coefficients of the effect of perennial forage crop area on arable land reflect the amount of nutrients, especially nitrogen, with which these crops (clovers, clover-grass mixtures) enrich the soil. Vostal (1994) gave a corrected N rate of 50 kg.ha^{-1} after a good-quality clover crop and 25 kg.ha^{-1} after a clover-grass mixture for the first year.

In case soil enrichment after perennial forage crops is considered for the upper limit of 50 kg.ha^{-1} from the area of perennial forage crops, the respective coefficient *X* for the whole area of arable land would be 0.5 only, which does not agree with our findings. It is evident that our calculated coefficients of the effect of perennial forage crop percentage (*X*) in the range from 0 to 1.47 involve, mainly in the upper limits, other favorable effects without any detailed quantification exerted by clover crops and clover-grass mixtures on other crops. These are the effect of mobilization of other nutrients (P, K, Ca), improvement of soil structure and soil water regime, reduction in weed infestation, etc. Kolář and Kužel (1999) stressed the importance of primary organic matter as a source of energy for soil microorganisms that are vectors of the biological activity of soil. Soil cultivation also plays an important role because pH value decreases in untilled soils accompanied by a decrease in microbial activity. Kubát and Klír (1999) estimated the yield-forming action of soil decomposable organic matter as 5% on loamy soils and 10% on sandy soils. The important role of perennial forage crops in crop rotation should be stressed because according to Trávník and Richter (1999) the equalized balance of nutrients would currently be reached in the CR at inputs of about 215 kg.ha^{-1} pure nutrients per hectare.

Our results should not be generalized to establish any extreme correlations or to apply them to different agro-ecological conditions. It is stated by Vrkoč and Vach (1995) that the subsequent effect of clover crops and clover-grass mixtures is a function of nitrogen if the system has enough moisture. This statement also elucidates the variable effect of clover crops, especially alfalfa, in arid regions. It is necessary to agree with objections that the model does not involve the effect of root crop percentage in crop rotation and/or other effects. Root crops – potatoes were produced in less than 50% of the farms, sometimes on 2% of arable land only. To estimate – quantify such an effect, a considerably larger set should have to be available, more data should have to be processed, and probably other statistical methods should have to be used (e.g. estimation of the effect by coefficient of determination).

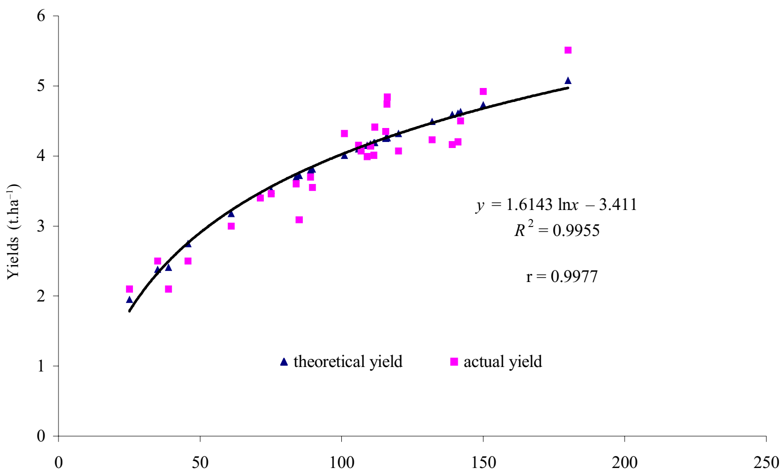

Figure 2. The effect of fertilization and perennial forage crop percentage on grain yield (the effect 0; 1.47); the sum of fertilization (kg NPK.ha^{-1}) + 1.47 × percentage of perennial forage crops on AL

These results indicate one of the possibilities how to stabilize yields of fodder grains, and evidently, other crops, in marginal – submontane regions at lower costs. Perennial forage crops on arable land in submontane regions are not only the basic condition for cattle raising but also an important stabilization factor of crop production at lower costs.

This study was a part of Research Project No. 412 1 0000 2 of the Ministry of Education, Youth and Sports.

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Received on November 19, 2001

ABSTRAKT

Vliv zastoupení víceletých pícnin na výnosy obilnin v podhorských oblastech

V letech 1996 až 2000 byla analyzována strukturální skladba rostlinné a živočišné výroby včetně ekonomických efektů 15 zemědělských podniků v podhorských oblastech. Byly zpracovány optimální modely rostlinné výroby pro podhorské oblasti Čech, včetně návaznosti na chov zvířat – skotu. Jako základní ukazatel stavu rostlinné výroby byl v období pěti let hodnocen výnos obilnin, který nejpřesněji charakterizuje úroveň agrotechniky. Hodnocením korelačních vztahů mezi výnosy obilnin a úrovní hnojení na orné půdě (NPK v čistých živinách na 1 ha) byla zjištěna přímá závislost mezi výnosem obilnin, hnojením NPK a podílem víceletých pícnin (jetelovin a jetelotrav) na orné půdě. Míra vlivu vyjádřená koeficientem korelace v jednofaktorových závislostech (výnos – hnojení, výnos – podíl pícnin) nebyla vysoká. Svědčí o tom vztah mezi dávkami NPK do 100 kg.ha^{-1} orné půdy a výnosem obilnin. Podobně tomu bylo i při rozboru vztahů mezi podílem víceletých pícnin na orné půdě a výnosy obilnin. Řešením těchto dvou rovnic byla vyjádřena míra vlivu jak hnojení NPK, tak podílu víceletých pícnin na výnos obilnin výslednou rovnicí: výnos obilnin v t.ha^{-1} = log^2 (dávka NPK v kg.ha^{-1} orné půdy + X% × podíl víceletých pícnin). Míru vlivu víceletých pícnin pak představuje výraz: X% × podíl víceletých pícnin, kde průměrná hodnota celého souboru $X = 0{,}95$. Tento vliv lze zdůvodnit obohacením půdy dusíkem, mobilizací dalších živin, zlepšením půdní struktury i snížením zaplevelení půdy. Přírůstek výnosu obilnin vlivem zastoupení víceletých pícnin byl kvantifikován z celého souboru dat uvedenou rovnicí hodnotou +0,42 t.ha^{-1}, a to jako rozdíl mezi skutečným průměrným výnosem souboru a teoretickým průměrným výnosem při nezapočítání vlivu pícnin ($X = 0$). Při zápočtu pícnin ($X = 0{,}95$) činil rozdíl mezi skutečným a teoretickým výnosem pouhých 0,01 t.ha^{-1}. Na 1 kg NPK.ha^{-1} orné půdy připadá přírůstek výnosu 0,0501 t.ha^{-1}, každé 1% pícnin na orné půdě zvyšuje výnos obilnin o 0,023 t.ha^{-1} v rámci hodnoceného souboru. Míru závislosti mezi skutečným a teoretickým výnosem celého souboru při hodnocení míry vlivu víceletých pícnin koeficientem $X = 0{,}95$ dokazuje korelační koeficient ($r = 0{,}9332$), při hodnocení míry vlivu koeficientem $X = 1{,}47$ je korelační koeficient ještě vyšší ($r = 0{,}9977$). Regresní rovnice pro tuto nejvyšší závislost má tvar: $y = 1{,}6143 \ln (X) - 3{,}411$. Pokud počítáme pouze vztah mezi hnojením NPK a výnosem, je hodnota korelačního koeficientu $r = 0{,}8791$.

Klíčová slova: marginální oblasti; výnosy obilnin; hnojení NPK; zastoupení víceletých pícnin

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