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A DECISION SUPPORT SYSTEM FOR THE SELECTION OF MAIZE (*ZEA MAYS* L.) SILAGE HYBRIDS IN THE NORTHWEST OF PORTUGAL

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ABSTRACT: *Maize (Zea mays L.) silage is of major importance to milk production in the agricultural system of the Entre-Douro e Minho, a province in the northwest of Portugal. Farmers typically have a variety of maize hybrids to choose from according to cycle length and planting date. The general rule is to use longer cycles for earlier planting dates and vice-versa. These decisions (planting date and maize cycle length) and the particular year's temperature regime will determine harvesting date. Since weather is unknown at planting date, there is the need to establish decision support rules based on historic weather data to help farmers optimise silage production. Silage production optimisation means a better matching between three variables - planting date, hybrid maize cycle length and harvesting date -, in order to produce more quantity of higher quality silage. Others variables that also need to be considered in this problem, are the available days to perform all crop operations and the field working capacity of the farm machines available to do it. We have used data from a 3-year experiment involving 5 planting dates and 6 length cycles (FAO 200 to 700) in order to establish decision support rules. Those decision rules were than translated and incorporated into a simple and friendly-use graphical manner (abacus) in order to support farm extension services of the Entre-Douro e Minho region.*

KEYWORDS: decision support system, selection of maize, Zea mays L, silage hybrids, in northwest, Portugal.

INTRODUCTION

Maize (*Zea mays* L.) silage is a major crop in the smallholder maize-dairy agricultural system of the Entre-Douro e Minho region in the northwest of Portugal, where over 60 thousand hectares are planted each year. In the past, planting date was delayed until late May or early June for several reasons: 1) time was needed for spring ploughing; 2) soils were warmer at later dates, contributing to the success of less vigorous races or hybrids; 3) pre-planting tillage facilitated weed control. As more vigorous hybrids came into use along with herbicides, planting dates for maize were

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anticipated. The optimum date to planting varies from year to year so that, every single year, producers are faced with the decision of which hybrid to plant according to the objective of maximizing yield and quality.

The selection of maize hybrids in relation to the timings of planting and harvest are important management decisions for maize silage operations and dairy production. Field management practices used to produce maize silage are very much the same as those used for grain production in most areas, since the crop is often planted as double purpose (grain or silage).Nowadays maize hybrids may be planted during a wide season, from early spring to early summer. The choice of a planting date, all along in this period, conduces to a wide variability in yield and associated risk. In addition, adverse spring conditions, particularly high soil moisture content and low temperature regimes often push planting dates past the optimum for grain and, sometimes, silage production. Likewise, less-than-optimum conditions for grain production may force farmers to harvest maize for silage.

Although some general guidelines are well known by producers – like: the existence of major differences among the various cycle length maize cultivars; full-season hybrids, planted early, produce more biomass of better quality; later planting dates should use short-season hybrids in order to maximize silage quality; longer cycles planted late will not produce grain and, therefore, will have low quality; and, short cycles planted early will not maximize biomass production -, there is the need for more precise knowledge in order to optimise milk production.In the region, very few management studies have been conducted on planting dates or harvesting dates for maize silage, and none have studied both problems and interactions.Many studies have clearly point out that maize hybrids respond differently to planting dates (Heather and Lauer, 2002; Lauer *et al*., 1999; Graybill *et al.*, 1991; Fairey, 1980 and 1983). Along with recommended optimums, several researchers have described a quadratic maize yield response to planting date (Heather and Lauer, 2002; Lauer *et al.*, 1999; Nafziger, 1994; Johnson and Mulvaney, 1980).

The relation between maize silage yield and planting date has not been clearly established. However, it has been hypothesised that planting maize for forage could theoretically be later than for grain because forage harvest does not have to wait until the grain matures fully (Allen *et al.*, 1995; Heather and Lauer, 2002). For instance: Hicks *et al.* (1970) reported an interaction between a hybrid's growing season length and optimum planting date, with a full-season hybrid benefiting most from an early planting date and also suffering the most from a delayed planting date; Bunting (1978) reported no planting date x hybrid interactions; while Nafziger (1994) reported varying results dependent on the particular year; and, Heather and Lauer (2002) reported few significant hybrid x planting date interactions or hybrid differences.

Various experiments have documented the best time to harvest maize for silage to optimise yield and quality (Bal *et al.*, 1997; Coors *et al.*, 1997; Philippeau and Michalet-Doreau, 1997; Phipps *et*

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al., 1997; Russell, 1992; Weaver *et al.*, 1978). Wiersma *et al.* (1993) reported that maize silage quality is inversely related to stage of maturity at harvest.

Several authors have proposed the use of kernel milk line position as a gauge for optimal plant harvest moisture (Afuakwa and Crookston, 1984; Mueller *et al.*, 2001; Wiersma *et al.*, 1993). The general relationship is (Wiersma *et al.*, 1993): 66 % whole-plant moisture when the kernel milk line is half way from kernel crown to tip (point of attachment to cob); 63% whole-plant moisture when the kernel milk line is a three quarters way from crown to tip; and, 60% when milk line is at the tip or milk line isn't visible. The last stage is considered to be the lowest whole-plant moisture content at which good quality silage can be made.

Reported values of one-fourth to two-thirds kernel milk line position (65-68 % moisture) are considered the optimum stage of harvest to maximize intake, digestion, and milk production (Bal et. al., 1997). The ideal moisture concentration (65 to 70%) for ensiling maize closely coincides with the stage of development that ensures near maximum production of total digestible nutrients (TDN)/unit surface (Mueller *et al.*, 2001). Corn harvest outside this optimum range has a higher risk of reduced forage quality and poor silage preservation. Nevertheless, factors such as degree of packing, type of silo (horizontal versus vertical), and presence of additives can influence how wet the silage may be stored.

All these facts could be generally summarized and described by the two following Fig. 1 and 2.

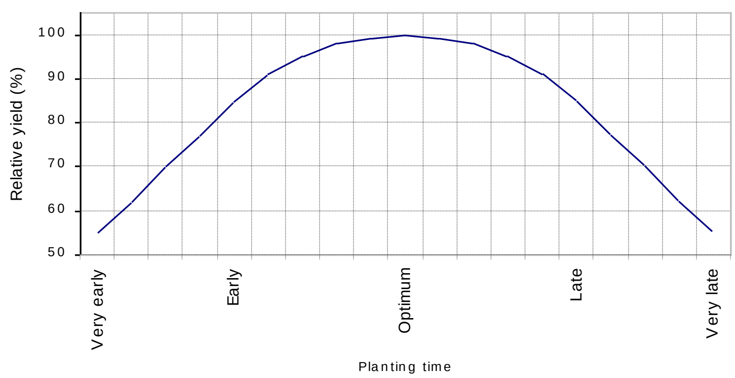

Fig.1. General curve effect of planting time on maize yield response

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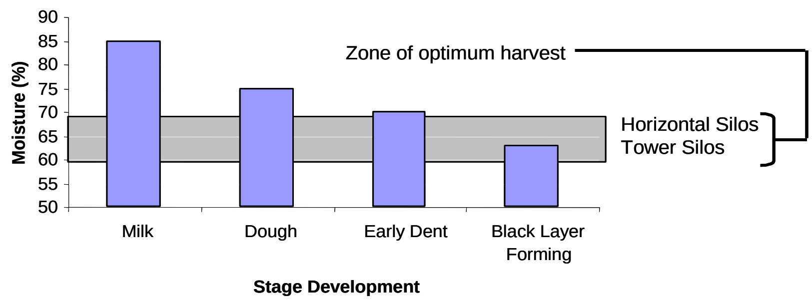

Fig. 2. The moisture concentration of the whole plant relative to kernel development and suitability for ensiling (From: Mueller et al., 2001)

Once a particular hybrid is selected and the crop is planted, producers also need to know the expected optimum harvest date. Since the actual weather year is unknown (particularly the temperature regime), producers can only have a rough estimate of harvest date given by seed companies in terms of number of days and not growing degree-units. Again, producers need more precise knowledge of harvest dates or, at least, be aware of the magnitude of variability that harvest date can have depending on the planting date and the hybrid used in order to better plan the harvest and the ensiling production operations. A good plan of ensiling operations should guaranty three essential tasks: rapid filling, tight packing, and proper sealing, in order to exclude air from the silage mass and to produce a good silage. Untimely delays during forage harvest can be costly because such delays almost always favour undesirable fermentation leading to dry matter losses and reduced feed quality of the resulting silage. Silo size and/or fill capability, witch depends on available forage quantity and quality and machine harvest capability and workability, should be such that a given silo can be filled in 1 to 3 days.

The optimal maize silage production management is the one that, for a given planting date, uses the hybrid that maximizes silage productivity and quality per unit area. On the other hand, once a particular planting date and hybrid are chosen, the producer should be able to have the distribution of possible harvest dates and consequent forage productivity and quality involved (the problem may also assume the inverse order, i.e. fixing de harvest date and the silage quality demanded). As we said before, the goal in making maize silage is to efficiently harvest and store the maximum amount of digestible nutrients per unit of land area (Undersander *et al.*, 1993). This requires that dry matter losses due to harvest and storage be minimized. The end result, high quality silage, is readily consumed by animals (dairy cows) and is capable (with proper supplementation) of inducing high levels of animal product (milk).

The objectives of this paper were to: (i) describe relationships between planting date and hybrid on maize silage yield and quality; (ii) describe relationships between harvest date and hybrid on maize silage yield and quality; and, (iii) determine optimum combinations of hybrids, planting dates and

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harvest dates for maize forage yield and quality in the northwest region of Portugal (Entre-Douro e Minho).

It is also our purpose, to integrate all this information into an analogical DSS (abacus type) for maize silage production optimisation in the agricultural system of Entre-Douro e Minho. This abacus will serve as a DSS for extension's services and maize silage producers of the Entre-Douro e Minho, in terms of recommending or deciding which FAO maize hybrid to plant on a given planting date and, doing so, what yield and harvest date intervals to expect (or the inverse problem). Such a tool is considered to be very useful for farm extension purposes, when compared to others more complex and less portable solutions (DSS software's, Expert Systems, etc.).

In the context of the Entre-Douro e Minho region, where the great majority of the farmers are very old (over 55 years old), poorly educated (less than 4 years of scholarship) and smallholders (average farm size is less than 5 hectares), a analogical DSS, very portable and easy to understand and consult, like an abacus, is seen as the adequate tool approach.

MATERIAL AND METHODS

The general methodology of this paper involves three consequent and inter-dependent steps: a) obtaining local field experimental data from 3-year trials; b) analyse and summarise the results of several distinct cultivars (from short to full-season hybrids), planted on consecutive planting dates (from early to late planting dates) and harvested on subsequent consecutive dates; c) integrate the decision support guidelines into a analogical and friendly use DSS (abacus).

Field Experiments

Field Experiments were conducted during 1995, 1996 and 1997 at the crop experimental field of the Escola Superior Agrária de Ponte de Lima (41º47'35''N; 8º32'38''W; 60 m Alt.) at Entre-Douro e Minho region (northwest of Portugal).The soil was a Cumulic Anthrosols (in the FAO classification system) or Entisols (in the American classification system), with depth of 150 cm and an average of 145 mm/m of measured plant available water. Main soil characteristics were: bulk density of 1.25; field capacity of 25.5%; and 13% permanent wilting point. The field was cultivated with the local traditional cropping system, integrating a winter cereal forage crop - ray grass + oats mixture (*Lolium multiflorum* + *Avena sativa*) and a spring/summer maize forage crop.

The experimental design was a randomised complete block in a split plot arrangement with three replications. In the 1995 year, main plots were five planting dates and one respective FAO maize hybrid (from FAO600 to FAO200) spaced at approximately 15-days intervals from 20 April to 19 June. Split plots were three harvest dates, corresponding to 75, 67,5 and 60,0% plant moisture stages. In total, the 1995-year trial involved 45 plots (5 planting dates x 3 harvest dates x 3 repetitions). The main purpose of this first year experiment was to study the influence of planting date and harvest date on maize forage development, yield and quality of each FAO maize hybrid.

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In the 1996-year, main plots were five planting dates spaced at approximately 15-days intervals from 23 April to 19 June. Split plots were three to four FAO maize hybrids ranged from full-season to shorter season maturity (FAO700 to FAO200). Harvest dates, were fixed to correspond approximately to the 67,5% plant moisture stage (the optimum stage of harvest to maximize intake, digestion, and milk production, according to Bal et. al., 1997). The objective of this field experiment was to compare the performance of three to four hybrids planted in the same date. In total, the 1996-year experience involved 54 plots.

Finally, in the 1997-year, main plots were five planting dates spaced at approximately 15-days intervals from 23 April to 18 June. Split plots were four to six FAO maize hybrids ranged from full-season to shorter season maturity (FAO700 to FAO200). Harvest dates, were fixed to correspond approximately to the 67,5% plant moisture stage. This experiment, involved a total of 72 plots, and its objective was similar to the previous year, being a confirmation year. Overall, a total number of 47 combinations of planting dates and hybrids were tested (Table 1).

Table 1. Combinations of planting dates and cultivars tested in the experiment.

Weather Year	FAO class (Cultivar)	Planting dates
	FAO 600 (DEDRA)	Apr 20
	FAO 500 (LICÍNIO)	May 5
1995	FAO 400 (CAPITAN)	May 20
	FAO 300 (SAFARIS)	Jun 5
	FAO 200 (PACTOL)	Jun 19
	FAO 700 (DK743)	Apr 23; May 8
	FAO 600 (DEDRA)	Apr 23; May 8; May 22
1996	FAO 500 (LICÍNIO)	Apr 23; May 8; May 22; Jun 5
	FAO 400 (CAPITAN)	May 8; May 22; Jun 5; Jun 19
	FAO 300 (SAFARIS)	May 22; Jun 5; Jun 19
	FAO 200 (PACTOL)	Jun 5; Jun 19
	FAO 700 (DK743)	Apr 23; May 7; May 21
	FAO 600 (DEDRA)	Apr 23; May 7; May 21; Jun 4
1997	FAO 500 (LICÍNIO)	Apr 23; May 7; May 21; Jun 4; Jun 18
	FAO 400 (CAPITAN)	Apr 23; May 7; May 21; Jun 4; Jun 18
	FAO 300 (SAFARIS)	May 7; May 21; Jun 4; Jun 18
	FAO 200 (PACTOL)	May 21; Jun 4; Jun 18

In all the experiments, other than factors treatments, all plots were managed by practices similar to those used by producers in the surrounding area of the location, and irrigation and nitrogen fertilization were guaranteed to be non-limiting for growth conditions (Table 2).

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Table 2: General plots management characteristics and site description

	1995	1996	1997
Previous crops	Maize grain followed by ray grass + oats	Maize silage followed by ray grass + oats	Maize silage followed by ray grass + oats
Hybrid	FAO-600; FAO-500; FAO-400; FAO-300; FAO-200	FAO-700; FAO-600; FAO-500; FAO-400; FAO-300; FAO-200	FAO-700; FAO-600; FAO-500; FAO-400; FAO-300; FAO-200
Soil Fertility:			
pH	6,1	6,2	6,5
P_2O_5, mg/kg	64	122	151
K_2O, mg/kg	178	>200	>200
OM, %	3,6	3,2	3,6
Fertilizer			
N, kg/ha	287	294	297
P_2O_5, kg/ha	70	96	78
K_2O, kg/ha	70	42	42
OM, kg/ha	2500	2500	2500
Lime stone, kg/ha	-	3000	-
Herbicide	Before planting	Before planting	Before planting and after emergency
Pesticide application	Soil Worms	Soil Worms	Soil Worms and Noctuidea
Irrigation, mm/ha	168 to 300	175 to 342	201 to 267

Plot size was 3 by 8 m with four rows per plot. Plots were seeded at a variable rate of 9,6 (FAO700) to13 (FAO200) kernels/m^2 and then hand-thinned to 7,64 to 10,3 plants/m^2 at the stage when 5 to 7 leaf collars were visible (V5-V7) (Ritchie *et al.*, 1996) to achieve as near a uniform stand as possible.

The kernel milk line was used as a visible indicator of when to harvest (Wiersma *et al.*, 1993). Kernel milk line was determined by random sampling of five ears per subplot. Ears were broken in the middle, and kernel milk line was visually assessed by observation of the endosperm side exposed. Harvesting would have ideally begun when the kernel milk line was one-third (early dent) to half (1/2 milk line) the way from kernel crown to tip (point of attachment to cob) (R5.3 – R5.5) (Ritchie *et al.*, 1996). At this stage, the resulting plant moisture content was between 73 and 66%, which is considered to be near the optimal for silage fermentation on horizontal bunker silos (Wiersma *et al.*, 1993; Mueller *et al.*, 2001).

At harvest the plants (stalk, leaf and ear) of the middle two rows were manually harvested with a sickle at 5 cm height, and two samples of 5 consecutive plants each were collected. In one sample, whole-plant (stalk, leaf, and ear) fresh-weight and dry-weight (weighing fresh, drying at 70ºC until constant weight, and reweighing) was determinate. The second five-plant sample was weight, and ears (kernels and cob) were removed and the stover portion weight. The remaining plants were

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weighed, and discarded. Final stand, whole plant and stover moisture, and dry matter yield were determined. Maximum and minimum air temperature, precipitation and solar radiation were recorded at the field site using an automatic weather station. Daily growing degree units (GDUs) were calculated using equation [1]:

$$GDUs = [(T_{max} - T_{min})/2] - T_b \qquad [1]$$

Where T_{max} is the maximum daily temperature (upper limit of 30ºC), T_{min} is the minimum daily temperature (with a lower limit of 6ºC), and T_b is equal to 6ºC. To calculate accumulated GDUs, the daily GDUs were summed for the number of days of growth beginning at planting. This DGU calculation method (*Sommes des degrés-jours temperatures seuil* 6ºC), with T_b = 6ºC, was proposed by Cailliez, (1999) and Durand *et al.* (1982).

Each one of the different maize cultivars used correspond a FAO maize cycle (from FAO200 to FAO700). Hybrids were chosen by its yield performance on local National Catalogue Variety's Trials. The hybrids selected were those that obtained the best average performances (yield and stability) in the last four years of those trials (Table 3).

Table 3. Characteristics of the maize hybrids selected (average for the period 1994-1997)[1].

Hybrids	*Class FAO*	*$GDUs_6$*	*Harvest Date.*	*Dry Matter (%)*	*Dry Matter (Mg/ha)*	*Recommended Stands (plants/m²)*	*Nº Years*
DK743	700	1898	1 Oct	32,7	31,0	7,64	4
DEDRA	600	1802	25 Sept	31,6	32,1	8,49	2
LICÍNIO	500	1739	16 Sept	29,8	29,2	8,93	4
CAPITAN	400	1656	10 Sept	33,4	29,6	9,28	3
SAFARIS	300	1573	3 Sept	30,7	22,4	10,06	4
PACTOL	200	1437	24 Aug	28,1	20,9	10,30	4

Source: Regional Bulletin of Maize Forage Varieties (Nogueira, 2000).

All field plots results were, first, treated and summarized into four general descriptive variables: days of crop duration, accumulated GDUs from planting to harvest, plant dry matter content at harvest, and ears/stover ratios.In order to estimate milk/ha production, field experiment's biomass yield was converted into UFL energy (Unités Fourragères Lait – Milk Forage Unit) according to the French Energy System (Vermorel, 1988). The definition of 1 UFL is the amount of net energy given by 1 kg of Barley to a *standard lactating cow (Bos taurus),* with 600 kg of body weight, producing 25 kg of milk/day, at 4% fat, above its maintenance energy requirements (all energy

[1] $GDUs_6$ are average values per FAO class (planting and harvest dates were fixed for all hybrids of the same FAO class). Average planting date for the period and for all the cycles was the 7 of May.

exported as milk). The conversion of field plots biomass output into UFL energy was based on the relationships between silage quality, evaluated by its percentage dry matter content, and individual standard animal performance in terms of forage intakes, digestibility and milk production. The amount of milk equivalent of the harvested biomass was calculated with the following two equations (Fig. 3), derived from the results presented by Hoden *et al.* (1988).

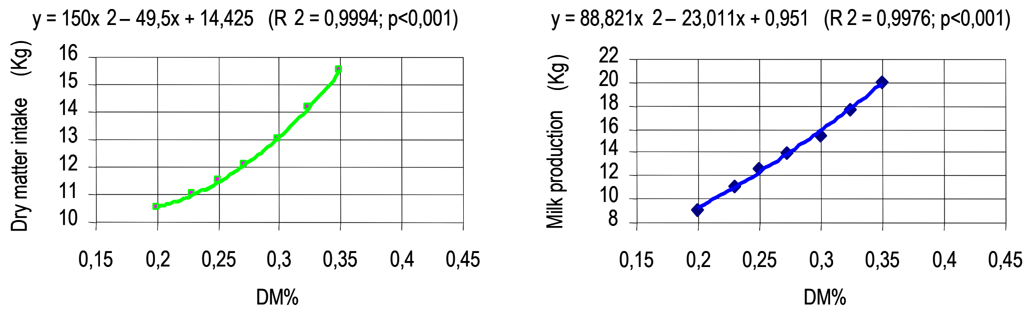

Fig. 3. Dry matter intake capacity (left) and milk equivalent production (right) by a *standard lactating cow* in *ad libitum* feeding regime, as a function of maize silage dry matter (%). Regression equations, determination coefficients (R^2), and probability levels (p).

As stated by several authors (Lauer, 1997; Ritchie *et al.*, 1996), the intake capacity and the milk production both reaches the maximum when maize silage dry matter content is near to 35%. For greater dry matter values, they rapidly decrease, because a loss of digestibility and a reduction on intake, due to less palatability of the product, occurs (Coors, 1997; Demarquilly, 1994). Because some of the forage of the field plots was harvested with more than 35% dry matter, we had to extend the two equations presented before, behind that limit. For doing so, we have used the characteristic alimentary values presented by Andrieu *et al.* (1988), for leaves and steams (stover), and ears. With that data we had estimated the functions represented in Fig. 4, which were only used to predict milk production in those extreme conditions (forage with more than 35% dry matter).

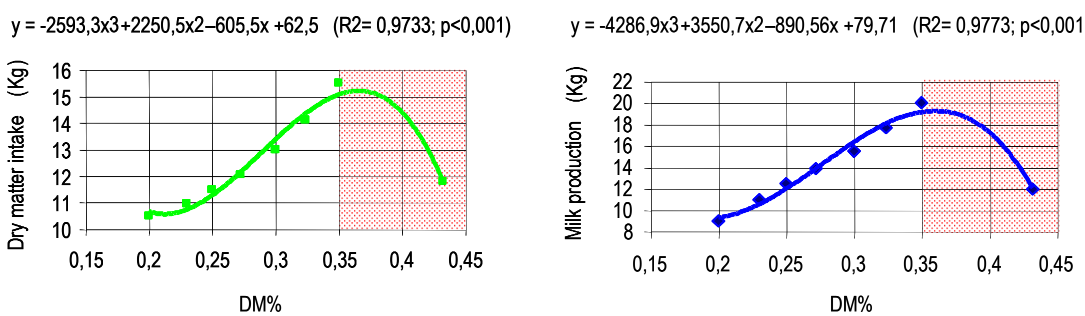

Fig. 4. Dry matter intake capacity (left) and milk equivalent production (right) by a *standard lactating cow* in *ad libitum* feeding regime, as a function of maize silage dry matter (%). Regression equations, determination coefficients (R^2), and probability levels (p).

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The LSD procedure was used to separate dry matter yield means and milk equivalent yield means of hybrids planted in the same day when the F-test was significant ($p<0,05$). Regression analysis was used to examine the relationship between planting date and ear/stover ratio, planting date and whole-plant dry matter yield and between GDUs and milk equivalent yield. Regression coefficients were described when significant ($p<0,05$). For each significant equation, maximum yields were obtained by calculating the first derivatives of the response equation to zero, solving for *x* (planting date or GDUs), substituting *x* into the response equation, and solving for *y*.

Data integration and DSS development

The development of the DSS followed four steps:

1) Prediction of milk equivalent yield (regression equations between whole-plant dry matter content and dry matter intake and milk production);
2) Estimation of the relationship between GDUs and milk equivalent yield (regression analysis);
3) Utilization of the average meteorological data from 20 years (1978-1997) on the region (Arcozelo, Meteorological Station) to establish the interaction between planting date, harvest date, and GDUs (abacus);
4) Construction of the global model of interaction between milk equivalent yield, GDUs, planting date and harvest date (abacus).

RESULTS AND DISCUSSION

Field results

The climate evolution of the three years was very similar (Fig. 5). However, during 1997, a cool June with the mean temperature around 15ºC, and a wet October with around 270 mm precipitation was observed. Accumulated growing degree units were about the same for the three years (2100º ± 100º GDUs).

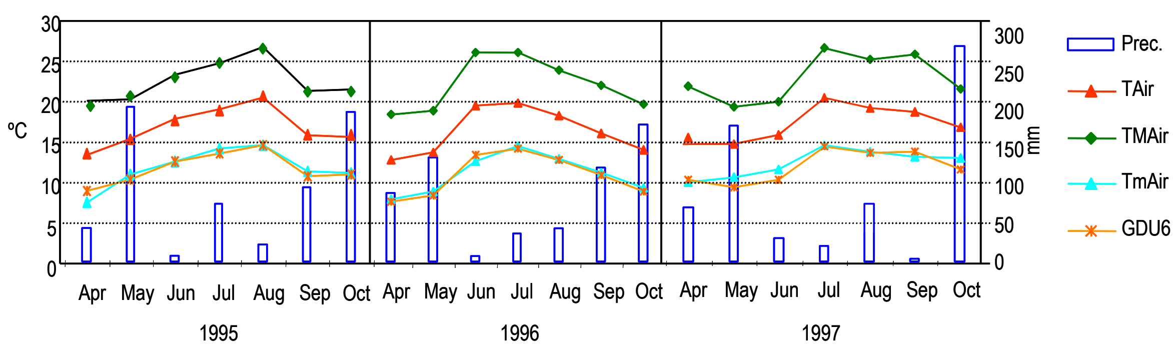

Fig. 5. Monthly values of precipitation (Prec.), mean (TAir), maximum (TMAir) and minimum (TmAir) air temperature, and growing degree units (GDU6, for t_b=6ºC).

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The dates of planting, days of crop duration, accumulated GDUs from planting to harvest, plant dry matter content at harvest, and ear/stover ratio at harvest are reported, as average values for the three years of experiments, in Table 4.

Table 4. Planting date, average crop duration, average accumulated GDUs, and average plant dry matter content at harvest for each FAO hybrid class used in this study (1996-1997).

FAO hybrid cycle	Planting date				
	Apr 23	May 7/8	May 22/23	Jun 4/5	Jun 18/19
	Crop duration (days)				
FAO700	154	148	138	-	-
FAO600	147	143	136	131	-
FAO500	141	139	133	125	120
FAO400	139	133	125	122	117
FAO300	-	132	121	119	110
FAO200	-	-	119	112	106
	Accumulated GDUs				
FAO700	1927	1902	1875	-	-
FAO600	1862	1841	1820	1794	-
FAO500	1770	1794	1785	1695	1666
FAO400	1749	1714	1708	1658	1635
FAO300	-	1699	1633	1634	1551
FAO200	-	-	1604	1539	1491
	Plant dry matter content at harvest (%)				
FAO700	34	31	34	-	-
FAO600	34	31	32	31	-
FAO500	32	31	33	31	34
FAO400	34	32	31	31	32
FAO300	-	35	36	33	30
FAO200	-	-	34	31	29
	Ear/stover ratio (g/kg)				
FAO700	563,3	558,8	563,6		
FAO600	574,0	537,7	547,6	552,8	
FAO500	577,3	570,7	560,3	516,1	508,8
FAO400	607,8	557,2	501,5	568,3	558,9
FAO300		601,3	613,3	574,0	533,1
FAO200			631,2	555,1	550,5

The crop duration and the accumulated GDUs variables reveal the expected digressive progression as time of planting increases (days of crop duration and GDUs in the same line) and as FAO cycle decreases (days of crop duration and GDUs in the same column). Whole-plant dry matter content at harvest shows that, in general, we had succeeded to control the ideal moment of harvest (dry matter between 30 to 35%). These results also suggest that maize planted at this range of dates may reach similar harvest maturities. Shorter hybrid cycles (FAO300 and FAO200) had larger changes in dry matter content at harvest (6 to 5%) across planting dates. Several researchers have suggested the

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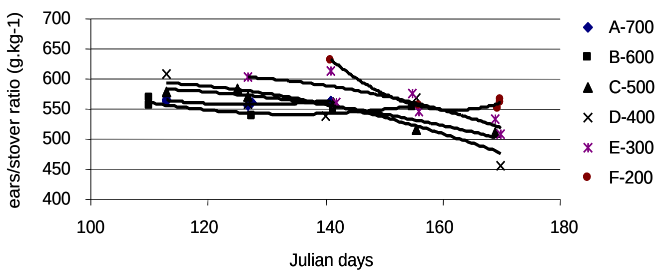
importance of the grain proportion of a maize plant to maximize forage dry matter content and quality (Phipps and Weller, 1979; Heather and Lauer, 2002).

The relation of planting date and ear/stover ratio was explained using a quadratic model in all hybrids (Fig. 6). The models aren't however stable. Maximum ear/stover ratio was observed in mid-May planting dates for the FAO200 hybrid. June planting dates reduced ear/stover ratio in all hybrids. These results may be explained by a stover yield increased in later planting dates.



Hybrids	Regression equations	R^2
FAO 700	$1,1761 - 0,0097d + 0,000004d^2$	0,843
FAO 600	$1,1371 - 0,0089d + 0,000003d^2$	0,744
FAO 500	$8,4355 + 0,0031d - 0,000002d^2$	0,924
FAO 400	$0,3461 + 0,005d - 0,000002d^2$	0,706
FAO 300	$0,1892 + 0,0071d - 0,000003d^2$	0,759
FAO 200	$5,4921 - 0,061d + 0,0002d^2$	0,978

R^2 are significant at the level of probability: p=0,05.

Fig. 6. Relationship between planting date (May 20 = 140 Julian day) and ear/stover ratio.

Relationships between planting day of the year and forage dry matter yield, and milk equivalent yield for each FAO hybrid class are reported in Table 5.

Table 5. Planting date, average dry matter yield, and average milk equivalent yield at harvest for each FAO hybrid class used in this study (1996-1997).

FAO hybrid class	Planting date				
	Apr 23	May 7/8	May 22/23	Jun 4/5	Jun 18/19
	Dry matter yield (Mg/ha) ($F_{(23,122)}$= 16,236; p<0,005)				
FAO700	24,38 *a*	23,39 *a*	20,31 *ac*	-	-
FAO600	24,65 *a*	24,31 *a*	23,01 *b*	23,16 *a*	-
FAO500	21,66 *b*	23,21 *a*	21,83 *bc*	22,03 *ab*	19,31 *a*
FAO400	16,25 *c*	19,48 *b*	19,80 *a*	19,73 *cd*	17,49 *ab*
FAO300	-	17,31 *b*	18,14 *a*	20,81 *bc*	17,34 *ab*
FAO200	-	-	15,74 *d*	18,20 *d*	15,88 *b*
	Milk equivalent yield (Mg/ha) ($F_{(23,122)}$= 9,318; p<0,005)				
FAO700	28,40 *a*	26,98 *ab*	25,65 *ab*	-	-
FAO600	31,13 *a*	27,28 *b*	26,99 *a*	28,64 *a*	-
FAO500	24,08 *b*	28,61 *b*	24,81 *ab*	25,44 *b*	24,14 *a*
FAO400	20,27 *c*	24,08 *ac*	24,16 *ab*	21,87 *c*	21,17 *ab*
FAO300	-	21,93 *c*	23,11 *bc*	26,04 *ab*	20,98 *ab*
FAO200	-	-	19,95 *c*	18,23 *d*	18,81 *b*

Means in the same column, and followed by the same letter are not significantly different at the level of probability of 5% by the LSD test.

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Planting date has been reported to significantly affect yield and yield quality of silage (Graybill *et al.*, 1991; Fairey, 1980; Heather and Lauer, 2002). From the comparisons of the means dry matter yield between the hybrids used in the same planting date we may conclude the existence of significant differences (evaluated by LSD test) among, at least, the longer and the shorter cycles. A significant planting date effect on whole-plant dry matter yield was seen for all the hybrids studied, and this relationship was best described with quadratic regression models (Fig. 7, and Table 6). The quadratic model shows significant ($p<0{,}005$) determination coefficients (R^2) and so it seams to be appropriated for describing the relationship between planting day and silage dry matter yield for all the tested hybrids. Among the hybrids studied, the optimum yield was realized between Julian days 115 (April 25 for FAO700 hybrid) to 156 (June 6 for FAO200 hybrid). Graybill *et al.* (1991) and Heather and Lauer (2002) also observed a progression of planting dates from April to late May across hybrid maturity classes for forage maize. The greatest yield was achieved with FAO600 hybrid, planted on Julian day 135 (May 15), and with a value of 24,7 Mg/ha.

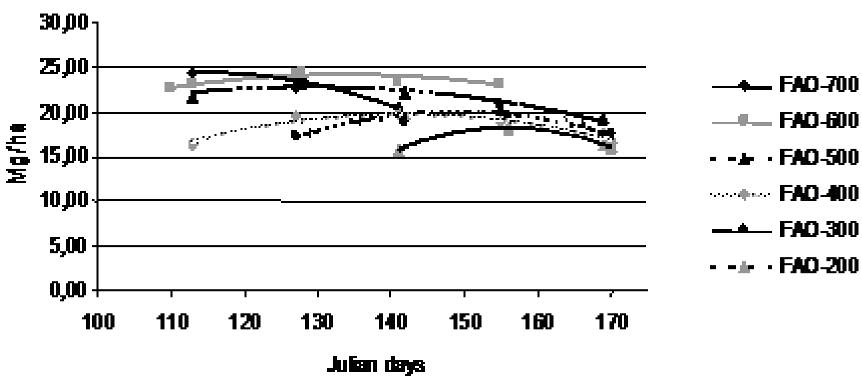

Fig. 7. Relationship between planting date (April 20 = 110 Julian day) and silage dry matter yield.

Table 6. Regression equations between planting day (d = Julian day of the year) and maize silage dry matter yield.

FAO hybrids	Regression equations	R^2	Day (d)	Maximum yield (Mg/ha)
FAO 700	$-50{,}296 + 1{,}3054d - 0{,}0057d^2$	0,939*	115	24,44
FAO 600	$-22{,}956 + 0{,}704d - 0{,}0026\ d^2$	0,758*	135	24,70
FAO 500	$-17{,}653 + 0{,}6256d - 0{,}0024\ d^2$	0,880*	130	23,11
FAO 400	$-53{,}548 + 1{,}0293d - 0{,}0036\ d^2$	0,911*	143	20,03
FAO 300	$-112{,}33 + 1{,}7737d - 0{,}0059\ d^2$	0,812*	150	20,98
FAO 200	$-248{,}76 + 3{,}4238d - 0{,}011\ d^2$	0,998*	156	17,66

* Significant at the level of probability: p=0,05.

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Planting date differences in whole-plant quality have been documented (Graybill *et al.*, 1991; Fairey, 1983; Heather and Lauer, 2002). Milk per unit of surface estimations from combining yield and quality into a silage term have been done (Undersander et. al., 1993). The milk/ha response to planting date is reported in Table 5. From the comparisons of the means milk yield between the hybrids used in the same planting date we may conclude the existence of significant differences (evaluated by LSD test) among, at least, the longer and the shorter cycles. The relationship between planting-date and milk/ha was not well explained using regression (linear or quadratic) models because the determination coefficients (R^2) of such models never reaches significant levels ($p<0,005$). To overcome this problem, we have decided to adjust a quadratic regression model between accumulated GDUs and milk equivalent yield. Table 7 and Fig. 8 presents the coefficients and the curve of the estimated quadratic equation, and points out the maize FAO hybrid better performance zone, in relation to the total amount of GDUs season accumulated.

Table 7. Regression Summary for Dependent Variable: Mg Milk/ha

R^2= ,735; Adjusted R^2= ,726; F(2,167)=225,16; p<0,0000; Std. Error of estimate: 2079,9

	BETA	St. Err. of BETA	B	St. Err. of B	t(167)	p-level
Intercpt			-132595,	22225,53	-5,96059	,00000
GDUs	5,54339	,858515	166,32	25,74	6,45695	,00000
$GDUs^2$	-4,72370	,858515	-0,0409	0,01	-5,50217	,00000

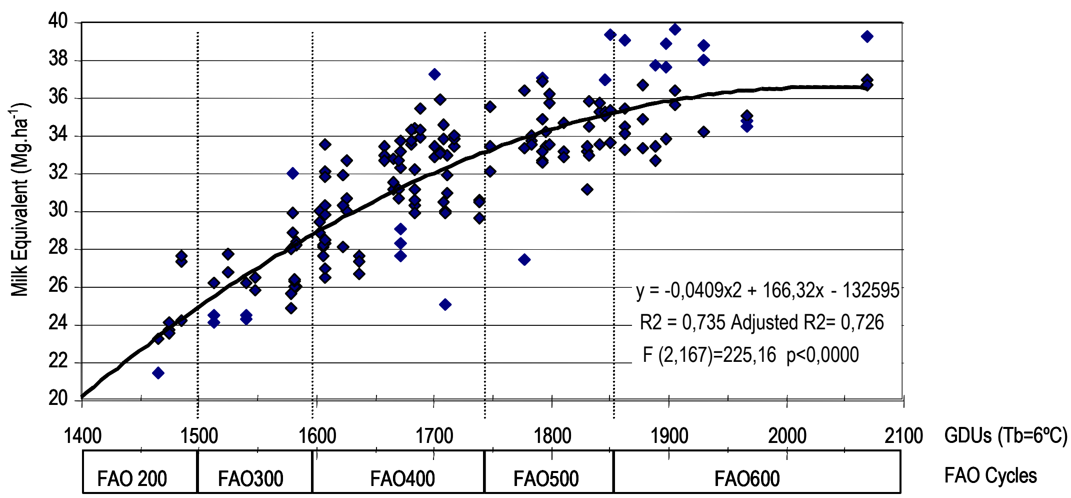

Fig. 8. Relationship (quadratic regression model) between GDUs and milk equivalent yield, and best performance maize FAO hybrids GDUs intervals.

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The quadratic model states the existence of a very significant relationship between accumulated growing degree units and milk equivalent yield. Milk equivalent yield continually increases from 1400 to 2000 GDUs. This, of course, is directly related with the combination of earlier planting dates, later harvest dates and full-season hybrids (Graybill *et al.* 1991; Heather and Lauer, 2002). Another interesting result is the fact that each maize FAO hybrid, appears to have its individual GDU niche interval. Longer cycles (FAO500 and FAO600) only reveal their entire yield potential in situations where growing degree units sum more than 1700. For the planting time interval that we have studied, from April 23 to June 19, FAO700 hybrid seam to be never recommendable one, as it is always yield overcome by FAO600 cycle. However, this conclusion should not be generalized outside the context of our particular experiment, because FAO700 class maturity hybrids may be or become interesting in the context, for instance, of earlier planting dates or future climate changes (temperature increase). Generally speaking, if maize-planting date is delayed until June 10 to 19, early maturing maize hybrids should be used.

These results also suggest the idea that growing several varieties with widely differing maturities (FAO200 to FAO600) will provide not only flexibility in planting but also in harvesting at the proper moisture content, and extent the "safe" harvest period. This is very important because numerous factors influence the decision of when to start planting maize. Rather than an exact date, soil condition is a key factor to consider. Planting when soil is too wet is not advised, regardless of the date. Under most circumstances, the best time to begin planting maize in Entre-Douro e Minho region is as early as conditions (soil and temperature) allow.

The mid-May seam to be the critical time from witch silage yields sharply decreases. How early one needs to begin planting maize in order to be completed by mid-May depends on soil conditions, hectares planted per day, work days available, and total number of hectares to be planted. In the region, during late April and early May, only about half the days normally are suited for field work (Coelho, 1992). A useful rule for estimating a start date for maize planting is to add up the number of days expected to plant all hectares plus the number of days of anticipated weather, mechanical, and personal delays, and back up that many days from May 8. That date should be a target date for beginning maize planting. From a practical standpoint, and given average climatic conditions in the region, April 10 to 15 is about the earlier planting date most farmers should consider.

MODEL DESIGN AND CONSTRUCTION

As we have said before, our purpose was to develop a model that provides solutions to real life problems, in the context of the Entre-Douro e Minho region. In this particular case, the model should help the extension services and the farmers to choose the maize hybrid to plant, given the planting date they are faced with, and subsequently to estimated the most probable, adequate and safe harvest date. For the construction of such a model we needed to establish the relationships between planting date and harvesting date. Because the relationship between those two variables is not a direct or a mechanistic one, we need to consider a third variable, directly related or dependent

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from those two. That variable is, of course, the growing degree units (GDUs). So with those three variables we have constructed the abacus reported in Fig. 9.

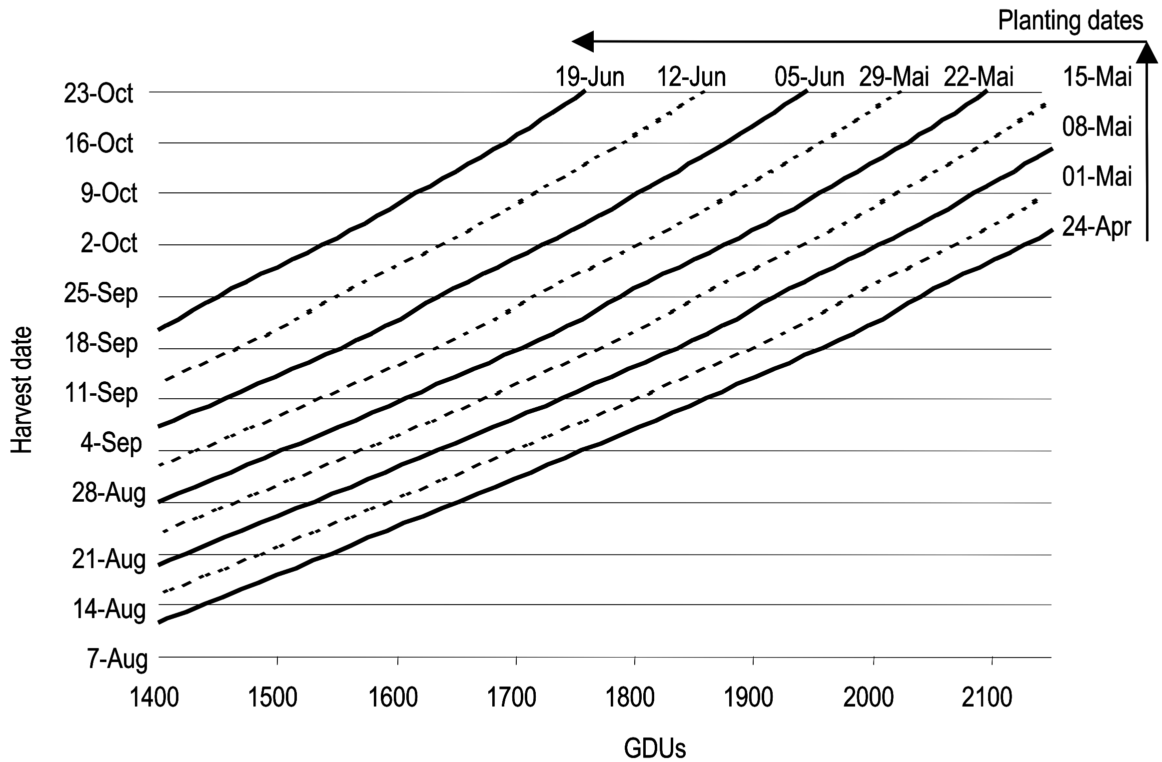

Fig. 9. Relations between planting date, harvesting date and GDUs.

In Fig. 9, each oblique line represent a planting date, and each horizontal line represent a harvest date (vertical axis). Each interception point of any of those two kinds of lines can be related with an average value of GDUs, from 20 years on the region, in the horizontal axis.
This abacus can be used in three manners: i) to anticipate the harvest date, having chosen the planting date and the FAO hybrid, because each FAO class as an approximately known GDUs exigency; ii) to decide the planting date, having fixed the latest harvest date and the FAO hybrid GDUs exigency; iii) or to anticipate the probable accumulated GDUs, having fixed the planting and the harvest dates.

With the combination of the two previous graphs (Figs. 8 and 9) we, finally, can construct the global DSS model for the management of planting date, harvest date and maize FAO hybrid on the region (Fig. 10).

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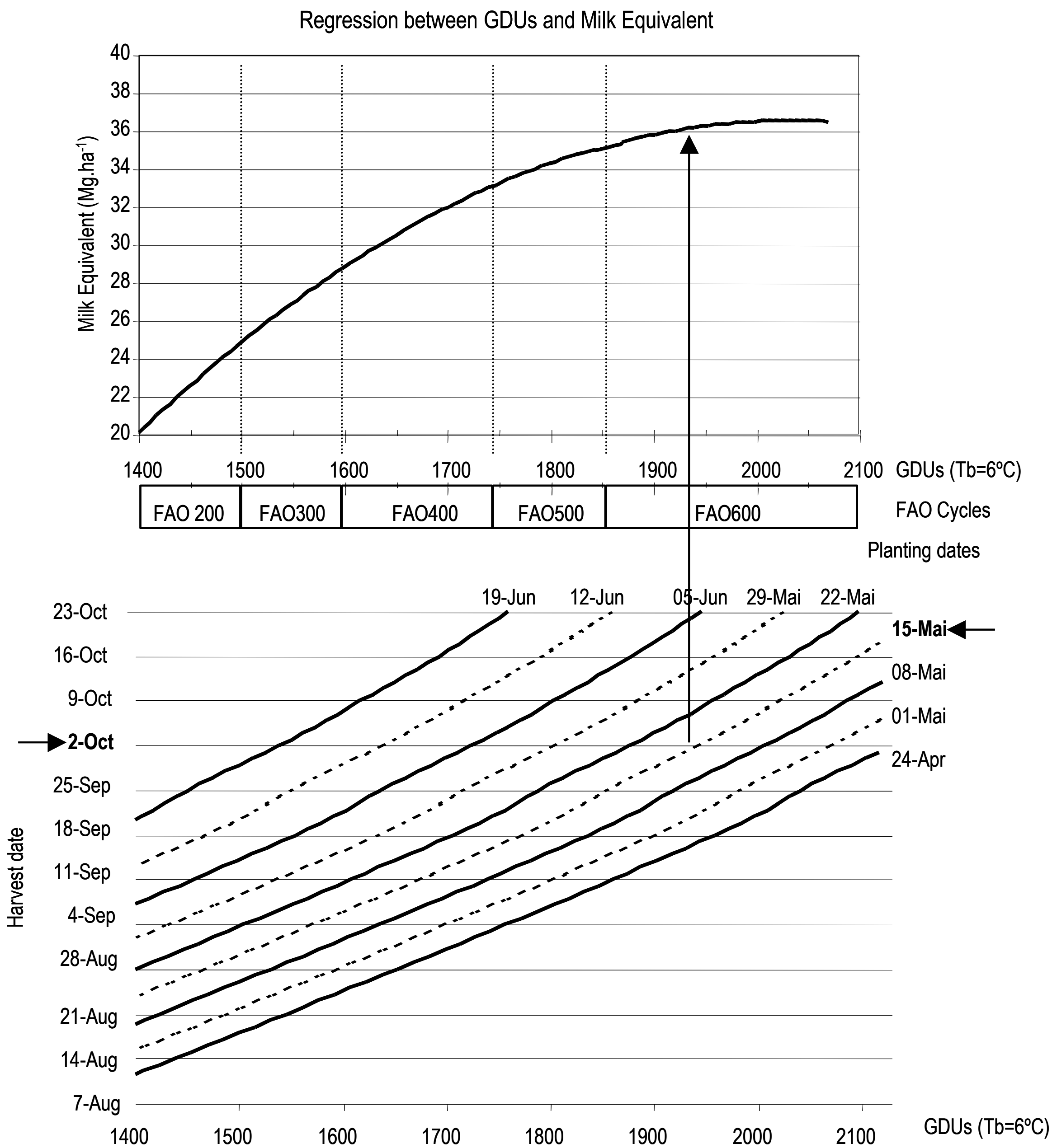

Fig. 10. Abacus for the integrated management of planting date, harvest date and maize FAO hybrid on the Entre-Douro e Minho region.

This abacus is very easy to use. For example, supposing that a given farmer in a particular field is ready to plant on the 15 of May. Let’s also suppose that the latest harvest date that he is willing to

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use, because of the risk involved on tractor and machines traficability on the field, is the 2 October. The question then is what FAO hybrid to use in order to maximize milk yield per unit area?
Using the abacus the problem is very easy to solve: first, in the inferior part of the abacus, choose the oblique line corresponding to May 15; secondly, choose the horizontal line corresponding to the harvest date October 2; next step consists on the determination of the interception point between the two lines; step four consists on moving up along a vertical line form the interception point to the quadratic equation in the superior part of the abacus. Now we have all the answers to our problem. We would recommend the use of a FAO600 hybrid and the farmer would expect to have a yield of 36 Mg/ha of milk equivalent.

Let's suppose another example: for instance that a given market responsible of seed-company A operating in the Entre-Douro e Minho region wants to program its maize seed stocks for the next campaign. Historical data supports the following facts: total maize regional market is about 60 thousand hectares; seed-company A detains approximately a 20% market share; planting season in the region normally goes on between May 1 to June 20, and seeded area along the season follows a Normal distribution function; and main objective pursuit by the farmers is the maximization of the milk yield per unit area. The question then is what and how much FAO hybrids should company A to stock?

Using the abacus one can see that farmers should use FAO600 hybrids from, approximately, May 1 to June 12. From then on they should use FAO500 hybrids. Given this information we can easily conclude that z =0,807, and F(z) = 0,8078. So the market responsible of seed-company A should stock enough FAO600 seed to plant approximately 9700 hectares, and enough FAO500 seed to plant approximately 2300 hectares.

CONCLUSIONS

A significant planting date effect on whole-plant dry matter yield was seen for all the hybrids studied, and this relationship was best described with quadratic regression models. Among the hybrids studied, the optimum yield was realized between Julian days 115 (April 25 for FAO700 hybrid) to 156 (June 6 for FAO200 hybrid). The greatest yield was achieved with FAO600 hybrid, planted on Julian day 135 (May 15), and with a value of 24,7 Mg/ha.

The relationship between planting-date and milk ha^{-1} was not well-explained using regression models. To overcome this problem, we have decided to adjust a quadratic regression model between accumulated GDUs and milk equivalent yield. From that model we predicted maximum milk equivalent production to be around 37 Mg/ha and optimum planting dates between 24 April and 22 May. The mid-May seam to be the critical time from witch silage yields sharply decreases. However, adverse spring conditions often push planting dates for maize past the optimum for silage production. Likewise, less-than-optimum conditions for forage production may force farmers to use short-season hybrids.

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The results of this study also suggest the idea that growing several varieties with widely differing maturity lengths (FAO200 to FAO600) will provide not only flexibility in planting but also in harvesting at the proper moisture content, and extent the "safe" harvest-ensiling period.
Finally we can conclude that the model described in this paper provides a very easy and flexible methodology to use as a decision support system for the selection of maize (*Zea mays* L.) silage hybrids in relation to planting and harvest dates in the Northwest of Portugal. Moreover, we believe that the conceptual model developed in this paper as a potential of extrapolation to others environmental contexts.

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