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Forage Conditioning Under Alpine Environmental Conditions

L. Benvenuti;* R. Cavalli;* A. Ott†

* Dipartimento Territorio e Sistemi Agro-Forestali, Università degli Studi di Padova, Italy

† Eidgenössiche Forschungsanstalt für Betriebswirtschaft und Landtechnik, Tänikon, Switzerland

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In mountain areas the location of the field can affect the climatic and vegetative conditions, and the operational characteristics of forage harvesters, thus influencing the effectiveness of crop conditioning. A method was established to compare the results from successive harvests through forage conditioning trials, carried out according to the vegetation and operational conditions of the field. A conditioning coefficient, defined by the relationship between the conditioned and non-conditioned forage, was used to define the effect of conditioning on the moisture evaporation process.

Forage conditioning was found to be highly effective on fields where the combined effect of slope and exposure was to increase the intensity and duration of solar radiation; the benefit of forage conditioning was severely reduced in other cases.

1. Introduction

Intensive meadow cultivation requires that the forage, once cut, be quickly removed from the field. This ensures rapid regrowth of plants which is otherwise suppressed by drying forage lying on the meadow. Quick removal also reduces substantially the risk of quality loss due to rain damage.

To increase the timeliness of harvest and thus protect the quality of the forage and the productive potential of the sward, mechanical means can be used for conditioning with the aim of accelerating the drying process. Conditioning creates lesions on the plant which speeds up water loss and reduces the intensity and length of catabolic phenomena which persist even after cutting and which reduce forage quality.

With conditioning machines the action of two counter rotating rollers or fingers on a tined rotor causes abrasion and breakage of the forage as it passes through the conditioner; the hardest parts, such as the stems, are particularly affected. In effect, the conditioning action produces folds, lacerations and squashing which create lengthways cracks in the stem where moisture evaporates more readily.

The efficiency of the conditioning operation can be altered by intrinsic machinery factors, such as adjustment of the conditioning device, and environmental factors, such as climatic variables and, in an alpine environment, the location of the plots of land on the slopes. In particular, the position of the meadow can alter climatic, vegetative and working conditions, which in turn lead to variability in the results of the haymaking operations and affect the evaporation of water from the forage.

The agricultural use of mountain areas has commonly meant the cultivation of valley floors and south-facing slopes. The most inaccessible areas and those facing north are left covered by forest. Nevertheless, there are many plots of land used for cultivation as meadow that are characterized by a high altitude slope and a northern aspect, sometimes due to the irregularity of the slope. Recently, the necessity of producing on the farm all the forage necessary for rearing the herd during the winter has prompted the agricultural use even of land previously not considered suitable for farming.

Such considerations have given impetus to analysis of the efficiency of the conditioning operation as affected by topography of the land, leading to controlled experiments on fertile meadows in alpine areas.

The specific objectives of this study were:

(i) to develop methods to analyse under alpine environmental conditions:
the evaporation of water from forage;
the effects of conditioning of forage; and
the influence of field position (exposure and slope) on the evaporation process

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Table 1
Agronomic conditions of the meadows

Trial	Type of meadow	Harvesting period*	Floral composition: Gramineae, %	Legumes, %	Other plants %	Grass yield at first harvest, t d.m./ha	Forage dry matter content at mowing % w.b.
1	Natural	Normal	60	10	30	4.3	17.60
2	Natural	Normal	65	15	20	4·6	22·35
3	Seeded	Late	75	25	0	5·5	20·35
4	Natural	Early	50	20	30	2·5	20·90
5	Natural	Early	55	15	30	2·9	17·10
6	Natural	Early	50	20	30	3·3	16·20
7	Natural	Early	55	10	35	3·2	19·95

* Early harvesting = Gramineae early earing stage
Normal harvesting = Gramineae fully earing stage
Late harvesting = Gramineae ending earing stage

(ii) to determine the drying coefficient in different field positions both for conditioned and non-conditioned forage
(iii) to determine the advantage of conditioning for different field position.

2. Materials and methods

2.1 *Experimental details*

The experiment was carried out in the spring of 1991 on alpine dairy-forage farms, in permanent mixed meadows, some natural and some mixed, with altitudes between 550 and 800 m. Intensive grass cultivation of four to five harvests per year was used. Cattle slurry was the predominant source of plant nutrients. Details of the swards are given in Table 1 and productivity in the test area at the time of the first harvest, was between 2·5 and 5·5 t/ha of dry matter (d.m.) (Table 1).

A comparison of the evaporation of water from the conditioned forage and from the non-conditioned forage was carried out during the first harvest of the meadows, which were characterized by different inclinations and exposures (Table 2).

Conditioning of the forage was done with a 1·8 m wide disk mower-conditioner having two grooved rubber rolls. The mower was mounted on the rear of a four wheel drive reversible tractor with a nominal power of 47 kW.

The non-conditioned crop, which was cut with a two-wheel tractor equipped with a cutterbar mower, was taken from an area not less than 400 m^2, roughly in the centre of the section of the meadow being studied. It was envisaged that the haymaking process would normally include between three and four tedding operations, windrowing and harvesting of the forage at between 25 and 35% m.c.w.b. Completion of drying would be in a barn equipped for artificial ventilation. The average dry matter for all the trials at the time of cutting was 19·2% w.b. (s.d. 2·26% and coefficient of variation 11·8%).

Table 2
Orographic conditions of the meadows

Trial	Altitude a.s.l. m	Slope %	Azimuth* deg
1	580	17	200
2	580	22	270
3	520	18	350
4	740	30	160
5	720	23	20
6	760	30	230
7	780	10	125

a.s.l. mean altitude above sea level
* Variable exposure angle (*E*) from 0 to 360 deg clockwise from the south

Temperature and relative humidity of the air were measured in the field during the tests using a Salmoiraghi thermohygrograph model 1750/2. The instrumentation was placed inside a small meteorological screen set 1·5 m above ground on the meadow. Incident solar radiation was recorded by a Bellani pyranometer. The average wind speed was measured at 0·5 m above ground by a cup anemometer (Table 3). During the tests, no precipitation occurred.

The state of the drying process in the field was

Table 3
Weather conditions during the trials

Trial	*Maximum temperature, °C*	*Minimum relative humidity %*	*Total solar radiation, kJ/m²*	*Average wind speed, m/s*
1	20·0	39	43597	*
2	22·0	37	45340	*
3	26·0	47	36638	0·08
4	21·0	43	33749	1·11
5	21·0	27	55614	1·00
6	20·5	37	55785	1·37
7	22·0	35	39856	1·06

* Values not taken

measured by taking five to seven samples of conditioned forage and non-conditioned forage at the same time. The first set of samples were taken at mowing and the last set at harvesting. The other samples were taken every 2 to 3 h between 0900 and 1800 hrs (solar time).

2.2 *Method of analysing the evaporation process*

The drying process of the forage is characterized by a sinusoidal variation due to the partial rehumidification in the field during the night. It has been verified that at a certain hour of the morning the forage shows the same moisture content as that recorded the previous evening.[1] For this reason, only the period between 09·00 and 18·00 hrs (solar time) is considered to be effective for the evaporation process (Luder[2]).

Studies of the speed with which the evaporation manifests itself, reveals that the evaporation rates decrease at a greater rate than the decrease of the moisture content in the forage. The mathematical model most suited to describe this kind of condition is the decreasing exponential one. Such a model is, in addition, suitable for representing the state of the drying process analysed as a function of a climatic index which is capable of expressing a measure of the drying capacity of the air.

With regard to this point, the information concerning the temperature and the relative humidity of the air gathered during the trials allows the saturation deficit of the air (SD, in g of water/m³ of air) to be calculated. This parameter, which expresses the difference between the quantity of water that the air can hold at saturation and that which is actually present in average temperature conditions, has been calculated using Bosen's equation as stated in Luder[2]

$$SD = p_{w(t)} - p_a \qquad (1)$$

where:

SD saturation deficit of the air, in g of water/m³ of air
$p_{w(t)}$ saturation vapour pressure at temperature t measured at a water surface, in Pa
p_a vapour pressure in the air, in Pa

The integral of SD with respect to time allows the summation of the saturation deficit (SSD, in g of water h/m³ of air) to be obtained and this allows the evaporation potential of the environment during the haymaking period to be expressed, using the Luder's equation[2]

$$M_t = M_o e^{\{-k_1(SSD_t) + [k^2(SSD_t)]^2\}} \qquad (2)$$

where:

M_t moisture content at time t, in kg water/kg d.m.;
M_o initial moisture content, in kg water/kg d.m.;
k_1 empirical constant, in m³ air/g water h;
k_2 empirical constant, in m³ air/g water h;
SSD_t summation of saturation deficit values accumulated at time t, in g of water h/m³ of air.

To analyse the efficiency of forage conditioning as a function of slope and exposure conditions of the meadow, it was necessary to adopt a methodology that allows both the position of the field and the state of the evaporation process to be expressed through coefficients. As far as the evaporation process is concerned, it was thought to be appropriate to simplify the exponential equation proposed by Luder[2] into the following

$$M_t = M_o e^{-k(SSD_t)} \qquad (3)$$

where:

k drying coefficient, in m^3 air/g water h.

This equation provides for the adoption of a drying coefficient (k) based on the integration of SD with time as a replacement for the coefficient based only on time.[3–6] Such a coefficient permits comparison of drying rates from the various trials, even if conducted during different time periods. These were required by the different working conditions and vegetative growth of the crop on the different farms. Both Eqns (2) (3) were used to fit the results, to see if the simpler equation was justified.

2.3 *Method of analysing the effects of conditioning*

The adoption of an exponential equation allows a comparison of the state of the evaporation process in conditioned and non-conditioned forage, using the analysis of the drying coefficient

$$E_m = k_c/k_{nc} \tag{4}$$

where:

E_m ratio of drying coefficients;
k_c, k_{nc} drying coefficients for conditioned and non-conditioned forage respectively, both in m^3 of air/g of water h;

as suggested by Savoie *et al.*[7] who, however, defined drying coefficients on the basis of the time the forage lay on the meadow. In particular, it can be seen that E_m expresses the benefit obtained from conditioning.

A second parameter, the conditioning coefficient, C, is given by the ratio between the SSD necessary to dry non-conditioned forage to a given moisture content, generally ranging from 30 to 70%, and the SSD necessary to dry conditioned forage to the same moisture content

$$C = SSD_{nc}/SSD_c \tag{5}$$

The determination of a conditioning coefficient allows evaluation of the benefit of conditioning, in terms of the reduction of the SSD requirement. The calculation of coefficients E_m and C has made possible, on the one hand, comparative analysis of results of trials and, on the other hand, research into a possible correlation with environmental characteristics, in particular, field position.

2.4 *Method of analysing the effect of field position*

Analysis of the influence of position of the field on the evaporation process and, specifically, on the benefit offered by conditioning, has been carried out using a coefficient capable of representing the position that a plane can assume with respect to the position of the sun. In particular, such a coefficient allows the rate of solar radiation (F, in W/m^2) incident on a piece of land to be defined as a function of the slope and exposure conditions through the following relationship

$$F = I_o G \tag{6}$$

where:

I_o represents the solar radiation that reaches an area exposed perpendicularly to the sun's rays, in W/m^2;
G insolation coefficient that expresses the position of the area with respect to the sun as a function of a series of geographical and astronomical parameters (Appendix A).

Analysis of the state of the coefficient G for different slopes as a function of exposure confirms that the influence of exposure becomes progressively greater with an increase in the inclination of the field. This influence is felt more intensely going from south to north. At 1200 hrs in June at a latitude of 45 deg the intensity of solar radiation reaching a field charac-

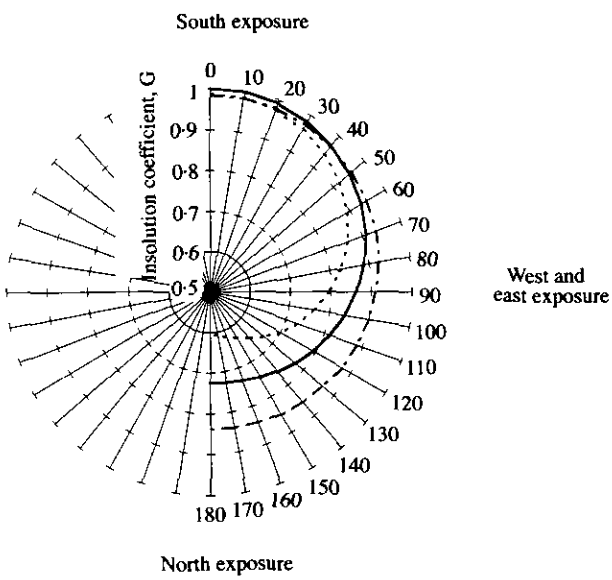

Fig. 1. Insolation coefficient G for meadow areas characterized by different surface inclinations, i (– – – – 59°; —— 68°; ····· 79°) and exposure, at 12·00 hrs in June and at a latitude of 45°N

Table 4

Relationship between the position of the field, represented by the insolation coefficient G, the values of the drying coefficients for conditioned forage, k_c, and for non-conditioned forage, k_{nc}, and the ratio of the drying coefficients, E_m

Trial	*G*	k_c m^3 *air/g water h*	k_{nc} m^3 *air/g water h*	$E_m = k_c/k_{nc}$
1	0·985	0·0221	0·0183	1·21
2	0·846	0·0181	0·0160	1·13
3	0·743	0·0166	0·0183	0·91
4	0·983	0·0245	0·0181	1·35
5	0·689	0·0166	0·0149	1·11
6	0·922	0·0212	0·0207	1·02
7	0·939	0·0225	0·0189	1·19

terized by a slope of 60%, corresponding to an inclination, i of 59 deg, and facing north is equal to about half of that received by a field with the same slope, but facing south (*Fig. 1*). Coefficient G, in addition, allows the time, in the arc of the day, in which a field characterized by a precise position "sees the sun" to be determined and therefore, also the insolation to which the field is subjected during the day or the year. Some more detailed results to a base of hour angle are given in Appendix A.

Given that the intensity of the evaporation process reaches its maximum during daylight hours, when solar radiation is at its most intense, the insolation coefficient G was calculated at 1200 hrs (solar time) for each trial (Table 4).

3. Results and discussion

The adoption of Eqn (3) simplifies the formulation of a drying coefficient capable of expressing the efficiency of conditioning and results in regression coefficients similar to those that can be obtained using Eqn (2) (Table 5).

Table 5

Regression coefficients (R^2) obtained using the Luder[2] (Eqn 2) and modified equation (Eqn 3)

	Conditioned		*Non-conditioned*	
Trial	*Luder Eqn (2)*	*Simplified Eqn (3)*	*Luder Eqn (2)*	*Simplified Eqn (3)*
1	0·976	0·988	0·997	0·997
2	0·998	0·951	0·999	0·985
3	0·998	0·998	0·994	0·991
4	0·990	0·987	0·928	0·922
5	0·985	0·953	0·997	0·984
6	0·990	0·990	0·978	0·973
7	0·997	0·963	0·995	0·962

In most of the trials, the drying coefficient was higher for conditioned forage than for non-conditioned forage. In only one trial, characterized by a very unfavourable position (G less than 0·75), was the drying coefficient greater for non-conditioned forage (Table 4).

Analysis of the drying coefficients shows, both for conditioned and non-conditioned forage, a positive correlation with the insolation coefficient G (*Fig. 2*). In particular, the regression line obtained for the conditioned forage is characterized by a slope about 2·5 times greater than that obtained for non-conditioned forage. Improvement of the field position brings with it, therefore, an increase of the drying coefficients and such an increase is greater for conditioned forage. Where the slope is unfavourable, conditioning does not bring any benefit to the water evaporation process from the forage and in such conditions may even be disadvantageous.

Analysis of the benefit obtained from conditioning

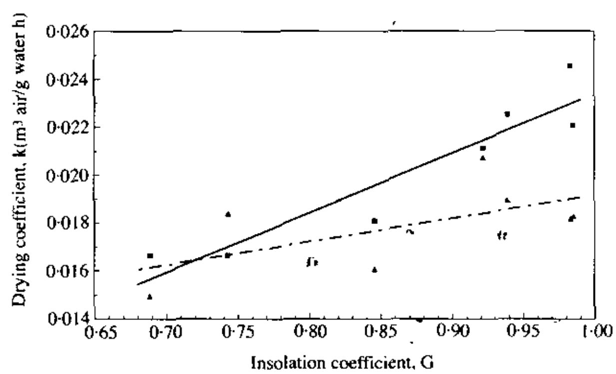

Fig. 2. Drying coefficient for the conditioned (k_c), ■, and the non-conditioned (k_{nc}), ◆, forage as a function of insolation coefficient G [Equation of regression line: $k_c = 0{\cdot}02489\ G - 0{\cdot}00148$; correlation coefficient = 0·936 ($P < 0{\cdot}01$); $k_{nc} = 0{\cdot}00971\ G + 0{\cdot}00946$; correlation coefficient = 0·602 (ns)]

has shown how the average efficiency of forage conditioning is high in fields where the combined action of the slope and exposure increases the intensity and duration of solar radiation (coefficient G more than 0·93). In other cases (coefficient G less than 0·93) the benefit offered by conditioning is considerably reduced (Table 4).

Analysis of the conditioning coefficient C (Table 6) shows how the benefit of conditioning tends to diminish with the duration of the evaporative process. In conditions where the position of the field is favourable, i.e. characterized by an insolation coefficient of more than 0.93, the coefficient C was between 1·28 and 1·41 with a moisture content at harvest of between 30 and 70% respectively. These values for the conditioning coefficient are comparable to those of Höhn,[8,9] Luder,[2] Granger *et al.*,[10] Augter.[11] In conditions where the position of the field is unfavourable, i.e. characterized by an insolation coefficient less than 0·93, the conditioning coefficient drops to 1·07–1·18 for the same forage moisture content at harvest (Table 6).

It can, however, be maintained that with a small number of tedding operations, the benefit of conditioning, in terms of smaller SSD requirement with respect to non-conditioned forage, could be even greater. In fact tedding produces abrasions and breakage similar to those caused by the conditioner. This tends to reduce the difference between conditioned and non-conditioned forage with regard to water evaporation. Spencer *et al.*[12] have noted a significant correlation between the benefit of conditioning and the number of tedding treatments. Specifically, the benefit expressed as a percentage relationship between the water evaporated from conditioned forage and that from non-conditioned forage decreased from 55 to 10% when the number of tedding operations rose from zero to six.

Table 6

Conditioning coefficient C ($C = SSD_{nc}/SSD_c$) as a function of forage moisture content at harvesting under favourable and unfavourable conditions of the field position, expressed by insolation coefficient G

	Forage moisture content % w.b.				
G	*30*	*40*	*50*	*60*	*70*
>0·93	1·279	1·287	1·300	1·325	1·414
<0·93	1·066	1·073	1·083	1·104	1·181

4. Conclusions

In the majority of comparisons, the evaporation process was more intense where the forage had been mowed and conditioned than where the forage had only been mowed. Analysis of the drying coefficient, k, showed some variability due to the position of the field. This was analysed by means of a coefficient capable of representing the position of the field with respect to the sun (insolation coefficient, G). It was found that there was a positive and highly significant correlation between the drying coefficient representing the evaporation process in conditioned forage and the coefficient G. Therefore, the position influenced, on the one hand, the evaporative process and on the other hand, the benefit offered by conditioning, which for values of G less than 0·75, tend to cancel out.

In conclusion, it was possible by means of the creation of a conditioning coefficient, to show the actual benefit offered by conditioning as a function of moisture content at harvest both for favourable and unfavourable positions. The results obtained demonstrate, therefore, the effectiveness of conditioning even if the high number of tedding operations carried out (between three and four) both on conditioned and non-conditioned forage have significantly reduced the differences in the evaporation process. It follows, therefore, that conditioning not only increases the rate of drying in favourable conditions, but could allow the number of tedding operations to be reduced.

Acknowledgements

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Appendix A

The coefficient G is the result of the combination of the geometrical components of vector I, which expresses the position of the sun with respect to a level surface, and those of the normal vector of the surface that describes the position with respect to the level surface. G is defined using the following relationship[13]

$$G = -\sin d \cos f \cos i \cos E + \cos d \sin f \cos H \cos i \cos E + \cos d \sin H \cos i \sin E + \sin d \sin f \sin i + \cos d \cos f \cos H \sin i$$

where:

d declination of the sun, in degrees;
f latitude, in degrees;
i inclination of the surface from 0 to 90 deg on the horizontal plane (note that in the above relationship the inclination of the surface is expressed as regard to vertical position);
E variable exposure from 0 to 360 deg clockwise from south;
H hour angle, in degrees.

Considering an horizontal surface ($i = 90°$), coefficient G depends only on a combination of geometrical components of vector I.

$$G = \sin f \sin d + \cos f \cos d \cos H$$

Considering a vertical surface, coefficient G is defined by the following equations, for the exposure angles given.

$i = 0°$; $E = 0°$ (south)

$$G = \cos d \sin f \cos H - \sin d \cos f$$

$i = 0°$; $E = 90°$ (west) and $E = 270°$ (east)

$$G = \cos d \sin H$$

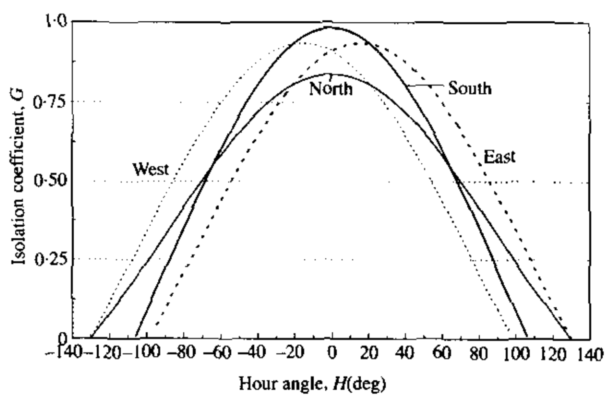

Fig. 3. Relationship between insolation coefficient, G, and hour angle, H, for different exposure situations, E and for a surface inclination, i, 79°, sun declination, d, 23° and latitude, f, 45°

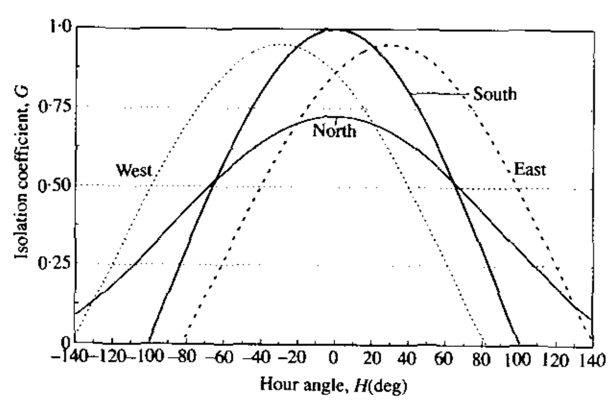

Fig. 4. Relationship between insolation coefficient, G, and hour angle, H, for different exposure situations, E, and for a surface inclination, i, 68°, sun declination d, 23° and latitude, f, 45°

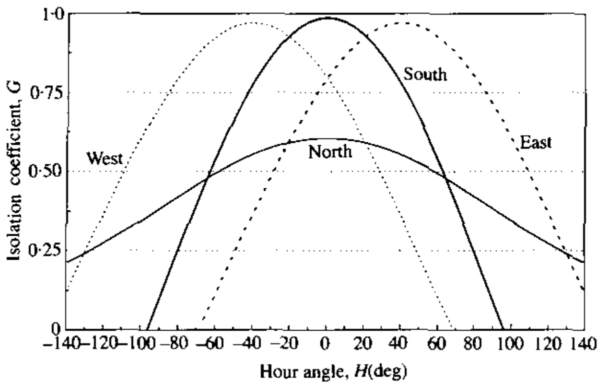

Fig. 5. Relationship between insolation coefficient, G, and hour angle, H, for different exposure situations, E, and for a surface inclination, i, 59°, sun declination, d, 23° and latitude, f, 45°

$i = 0°$; $E = 180°$ (north)

$$G = \sin d \cos f - \cos d \sin f \cos H$$

Figs *3* to *5* show the relationship between coefficient, G, and hour angle, H, for different exposure situations ($E = 0°$, south exposure; $E = 90°$, east exposure; $E = 180°$, north exposure; $E = 270°$, west exposure) and considering three inclination of the surface ($i = 79°$; $i = 68°$; $i = 59°$) (the correspondence between inclination and slope of the surface is shown below). Declination of the sun (d) and latitude (f) are constant ($d = 23°$; $f = 45°$)

Inclination, i	*Slope*
79°	20%
68°	40%
59°	60%