MAFCA - IICA

FIRST SHORT COURSE ON COMMUNICATION AND TECHNICAL WRITING

ELABORATION AND PRESENTATION OF STATISTICAL DATA

by

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MULTIPLE COMPARISON TESTS FOR SEPARATION OF MEANS

A LARGE NUMBER OF PROCEDURES HAVE BEEN DEVELOPED FOR TESTING THE DIFFERENCE AMONG SEVERAL MEANS. THESE INCLUDED THE FOLLOWING:

1. LEAST SIGNIFICANT DIFFERENCE.
2. DUNNET'S TEST.
3. TUKEY'S TEST.
4. DUNCAN'S MULTIPLE RANGE TEST.
5. NEWMAN KEULS TEST.
6. SCHEFFE'S TEST.

1. LSD. IN THIS TEST, THE DIFFERENCE BETWEEN TWO MEANS IS DECLARED SIGNIFICANT, AT ANY DESIRED LEVEL OF SIGNIFICANCE, IF IT EXCEED THE VALUE DERIVED FROM:

$$LSD = T.SJ$$

THIS TEST UTILIZES THE STANDARD ERROR OF A DIFFERENCE BETWEEN TWO MEANS. THIS TEST IS TO BE APPLIED ONLY WHEN THE F TEST IS SIGNIFICANT. (TABLE A.3).
THE LSD TEST IS VALID ONLY IN TESTING MEAN COMPARISONS WHICH WERE IDENTIFIED IN THE OBJECTIVE OF THE EXPERIMENT. I.E.

$$HO: \bar{X}A - \bar{X}B = 0 \qquad HA: \bar{X}A - \bar{X}B = 0$$
$$\bar{X}C - \bar{X}D = 0$$
$$\bar{X}E - \bar{X}F = 0$$

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
TREATMENTS	5	29.11	5.82	3.88
ERROR	12	18.00	1.50	
TOTAL	17	47.11		

$$DMS = 2.179 \sqrt{2*1.50/3} = 2.2$$

PLANNED COMPARISONS	DECISION
$\bar{X}A - \bar{X}B = 4.0 - 5.0 = -1$	(N.S)
$\bar{X}C - \bar{X}D = 6.7 - 7.0 = -0.3$	(N.S)
$\bar{X}E - \bar{X}F = 4.7 - 7.3 = -2.3$	(*)

2. DUNNETT'S TEST

DUNNETT'S TEST TREATS THE SPECIAL CASE OF COMPARING SEVERAL TREATMENT MEANS TO A CONTROL. ALTHOUGH THE OTHER TESTS IN THIS UNIT ARE ALSO CAPABLE OF MAKING THESE COMPARISONS THE DUNNETT TEST IS STRONGER --- MORE CAPABLE OF PICKING UP TRUE SIGNIFICANT DIFFERENCES BETWEEN MEANS. TO COMPARE TREATMENT MEANS X(C), AND X(I):

$$(\bar{X}(I) - \bar{X}(C)) - T\sqrt{2MSE/N} < U(I) - U(C) <$$

$$(\bar{X}(I) - \bar{X}(C)) + T\sqrt{2MSE/N}$$

WHERE:

N = COMMON SAMPLE SIZE FOR EACH TREATMENT GROUP OR THE AVERAGE SIZE DESCRIBED UNDER TUKEY TEST

T = CRITICAL VALUE OF DUNNETT STATISTIC (TABLE A.9B)

$\bar{X}(C)$ = MEAN FOR CONTROL GROUP

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
TREATMENTS	5	29.11	5.82	3.88
ERROR	12	18.00	1.50	
TOTAL	17	47.11		

$$\text{DUNNET} = 3.0 * \sqrt{2 * 1.50/3} = 3.0$$

PLANNED COMPARISONS	DECISION
$\bar{X}A - \bar{X}B = 4.0 - 5.0 = 1.0$	(N.S.)
$\bar{X}A - \bar{X}C = 4.0 - 6.7 = 1.7$	(N.S.)
$XA - XD = 4.0 - 7.0 = 3.0$	(N.S.)
$\bar{X}A - \bar{X}E = 4.0 - 4.7 = 0.7$	(N.S.)
$\bar{X}A - \bar{X}E = 4.0 - 7.3 = 3.3$	(*)

3. TUKEY TEST

THE TUKEY TEST IS USEFUL WHEN IT IS DESIRABLE TO MAKE ALL POSSIBLE COMPARISONS AMONG THE TREATMENT MEANS. THE PROCEDURE COMPUTES A SINGLE VALUE CALLED A "LEAST SIGNIFICANT DIFFERENCE" OR LSD AGAINST WHICH ALL COMPARISONS ARE MEASURED. THOSE COMPARISONS WHICH EXCEED THE LSD ARE SAID TO BE STATISTICALLY SIGNIFICANT. THE LSD IS GIVEN BY:

$$LSD = Q(A,K,DF)\ \sqrt{MSE/N}$$

K = NUMBER OF TREATMENT MEANS.
N = NUMBER OF REPETITIONS OR NO. OF BLOCKS.
DF = NUMBER OF DEGREES OF FREEDOM FOR MSE
MSE = MEAN SQUARE ERROR IN THE ANALYSIS OF VARIANCE TABLE
A = LEVEL OF SIGNIFICANCE OF THE TEXT
Q = STUDENTIZED RANGE STATISTIC WITH K AND DF DEGREES OF FREEDOM (TABLE 5)

IF THE SAMPLE SIZES (N(1),N(2),.....,N(K))FOR THE TREATMENT GROUPS ARE NOT ALL THE SAME THEN AN AVERAGE SAMPLE SIZE, N, IS USED WHERE:

$$N = K/1/N(1) + 1/N(2) = \ldots + 1/N(K)$$

THE LSD TEST CAN ALSO BE PHRASED IN TERMS OF CONFIDENCE INTERVALS. TO COMPARE TREATMENT MEANS X(I) AND X(J) WE ESTABLISH THE INTERVAL:

$$(\bar{X}(I) - \bar{X}(J)) \pm Q(A,K,DF)\sqrt{MSE/N}$$

THOSE CONFIDENCE INTERVALS WHICH INCLUDE THE POINT ZERO REFLECT THE FACT THAT THE MEANS ARE NOT STATISTICALLY DIFFERENT AT THE LEVEL A, WHEREAS THOSE CONFIDENCE INTERVALS THAT DO NOT INCLUDE ZERO INDICATE THAT U(I) AND U(J) ARE STATISTICALLY DIFFERENT AT THE A LEVEL OF SIGNIFICANCE.

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
TREATMENTS	5	29.11	5.82	3.88
ERROR	12	18.00	1.50	
TOTAL	17	47.11		

TUKEY: $4.75\sqrt{1.5/3} = 3.36$

PLANNED COMPARISONS	DECISION
$\bar{X}A - \bar{X}B = 4.0 - 5.0 = 1.0$	(N.S.)
$\bar{X}A - \bar{X}C = 4.0 - 6.7 = 2.7$	
$\bar{X}A - \bar{X}F = 4.0 - 7.3 = 3.3$	
$\bar{X}B - \bar{X}E = 5.0 - 6.7 = 1.7$	(N.S.)
$\bar{X}E - \bar{X}F = 4.7 - 7.3 = 2.6$	

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
TREATMENTS	5	29.11	5.82	3.88
ERROR	12	18.00	1.50	
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TUKEY: $4.75\sqrt{1.5/3} = 3.36$

PLANNED COMPARISONS	DECISION
$\bar{X}A - \bar{X}B = 4.0 - 5.0 = 1.0$	(N.S.)
$\bar{X}A - \bar{X}C = 4.0 - 6.7 = 2.7$	
$\bar{X}A - \bar{X}F = 4.0 - 7.3 = 3.3$	
$\bar{X}B - \bar{X}E = 5.0 - 6.7 = 1.7$	(N.S.)
$\bar{X}E - \bar{X}F = 4.7 - 7.3 = 2.6$	

4. DUNCAN TEST

THIS TEST IS IDENTICAL WITH THE LSD TEST FOR TWO MEANS BUT, ON THE OTHER HAND, REQUIRES PROGRESSIVELY LARGER "SIGNIFICANT VALUES" AS THE NUMBER OF MEANS INCREASES IN A GROUP.

$$DUNCAN._{(I)} = SSR._{(I)} * s\bar{X}$$

THE INFORMATION REQUIRED TO APPLY THIS TEST TO A SET OF DATA IS:

1. THE MEANS RANKED IN ORDER FROM LOWEST TO HIGHEST AS FOLLOWS:

A	E	B	C	D	F
4.0	4.7	5.0	6.7	7.0	7.30

2. THE STANDARD ERROR OF THE MEAN ($s_{\bar{X}}$), DERIVED FROM THE ERROR MEAN SQUARE.

$$s_X = \sqrt{EMS/N} = \sqrt{1.5/3} = 0.707$$

3. THE ERROR DEGREES OF FREEDOM (DF = 12)

4. THE SIGNIFICANT STUDENTIZED RANGES AT 5 OR 1% LEVEL. TABLE A.7

PROCEDURE: PREPARE A TABLE OF DUNCAN (I)

P:	2	3	4	5	6
SSR:	3.08	3.25	3.33	3.36	3.40
DUNCAN:	2.18	2.28	2.35	2.38	2.40

THE VARIETY MEAN DIFFERENCES ARE CONTRASTED WITH THE APPROPRIATE DUNCAN(I) I.E.: THE LARGEST DIFFERENCE WITH THE LARGES DUNCAN VALUE. DECIDE WHICH DIFFERENCES ARE SIGNIFICANT AND WHICH ARE NOT BASED ON THE FOLLOWING RULE:

THE RELATIVE NEWNESS OF DUNCAN'S RANGE TEST PRESENTS A PROBLEM TO THE INVESTIGATOR AS TO THE METHOD OF PRESENTATION OF EXPERIMENTAL DATA IN TABULAR FORM. DESIGNATION OF SIGNIFICANCE BETWEEN MEAN DIFFERENCE IN A TABLE MAY BE INDICATED IN TWO WAYS:

1. BY UNDERSCORING MEANS COMPRISING A GROUP THAT ARE NOT SIGNIFICANTLY DIFFERENT OR
2. BY THE USE OF LETTERS TO DIFFERENTIATE SIGNIFICANTLY DIFFERENT MEANS.

THE UNDERSCORING PROCEDURE FOR TWO DIFFERENT TYPES OF TABLES IS ILLUSTRATED IN TABLES 1 AND 2. THE DIFFERENTIATION OF MEANS WITH LETTER DESIGNATIONS IS PRESENTED IN TABLE 3.

THE APPLICATION OF THE UNDERSCORING PROCEDURE TO A SET OF DATA FROM A 2 X 6 FACTORIAL EXPERIMENT IS ILLUSTRATED IN TABLE 4.

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
TREATMENTS	5	29.11	5.82	3.88
ERROR	12	18.00	1.50	
TOTAL	17	47.11		

Duncan Multiple Range Test

First Short Course on Communication and Technical Writing.

4.00	4.70	5.00	6.70	7.00	7.30
0.00	0.70	1.00	2.70	3.00	3.30
			*******	*******	*******
0.00	0.00	0.30	2.00	2.30	2.60
					*******
0.00	0.00	0.00	1.70	2.00	2.30
0.00	0.00	0.00	0.00	0.30	0.60
0.00	0.00	0.00	0.00	0.00	0.30
0.00	0.00	0.00	0.00	0.00	0.00

SSR(i) =

0.00	3.08	3.23	3.33	3.36	3.40

LSR(i) =

0.00	2.18	2.28	2.35	2.38	2.40

Any Difference underscored by an aster is significant (P > .05)
Any Difference not underscored is not significant (P= or < .05)

5. NEWMAN-KEULS TEST

THE NEWMAN-KEULS TEST IS A MODIFICATION OF THE TUKEY TEST. IT HAS THE ADVANTAGE OF BEING A SLIGHTLY STRONGER TEST --- THAT IS, IT IS ABLE TO UNCOVER TRUE SIGNIFICANT DIFFERENCES THAT THE TUKEY TEST MIGHT MISS. HOWEVER, IT IS COMPUTATIONALLY A LITTLE MORE INVOLVED. INSTEAD OF A SINGLE LSD, THE NEWMAN-KEULS TEST USES SEVERAL LSD, THE FORMULAS FOR WHICH ARE:

$$LSD = Q(A,R,DF)\ \sqrt{MSE/N}$$

WHERE R = NUMBER OF MEANS IN THE RANGE OF THE COMPARISON
THAT IS TO SAY IF THE MEANS ARE ARRANGED FROM SMALLEST TO LARGEST AS:

$$\bar{X}(1) < \bar{X}(2) < \bar{X}(3) < \ldots\ldots\ldots < \bar{X}(K)$$

THEN A COMPARISON OF $\bar{X}(1)$ TO $\bar{X}(3)$ WOULD HAVE R = 3 (YOU PASS THROUGH THREE MEANS AS YOU COUNT FROM X(1) TO X(3): WHEREAS A COMPARISON OF $\bar{X}(2)$ TO $\bar{X}(6)$ WOULD HAVE R = 5, ETC.

AGAIN CONFIDENCE INTERVALS OF THE FORM:

$$(\bar{X}(I) - \bar{X}(J)) \pm Q(A,R,DF)\ \sqrt{MSE/N}$$

ARE USEFUL IN DECIDING WHICH DIFFERENCES ARE SIGNIFICANT.

NOTE: USE TABLE 5

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
TREATMENTS	5	29.11	5.82	3.88
ERROR	12	18.00	1.50	
TOTAL	17	47.11		

Newman-Keuls test

First Short Course on Communication and Technical Writing.

4.00	4.70	5.00	6.70	7.00	7.30
0.00	0.70	1.00	2.70	3.00	3.30
0.00	0.00	0.30	2.00	2.30	2.60
0.00	0.00	0.00	1.70	2.00	2.30
0.00	0.00	0.00	0.00	0.30	0.60
0.00	0.00	0.00	0.00	0.00	0.30
0.00	0.00	0.00	0.00	0.00	0.00

SSR(i) =

0.00	3.08	3.77	4.20	4.51	4.75

LSR(i) =

0.00	2.18	2.67	2.97	3.19	3.36

Any Difference underscored by an aster is significant (P > .05)
Any Difference not underscored is not significant (P= or < .05)

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
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ERROR	12	18.00	1.50	
TOTAL	17	47.11		

Newman-Keuls test

First Short Course on Communication and Technical

4.00	4.70	5.00	6.70	7.00	7.30
0.00	0.70	1.00	2.70	3.00	3.30
0.00	0.00	0.30	2.00	2.30	2.60
0.00	0.00	0.00	1.70	2.00	2.30
0.00	0.00	0.00	0.00	0.30	0.60
0.00	0.00	0.00	0.00	0.00	0.30
0.00	0.00	0.00	0.00	0.00	0.00
SSR(i) =		3.77		4.51	4.75
				3.19	3.36

aster is signif
not significant

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
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TOTAL	17	47.11		

Newman-Keuls test

First Short Course on Communication and Technical Writing.

4.00	4.70	5.00	6.70	7.00	7.30
0.00	0.70	1.00	2.70	3.00	3.30
0.00	0.00	0.30	2.00	2.30	2.60
0.00	0.00	0.00	1.70	2.00	2.30
0.00	0.00	0.00	0.00	0.30	0.60
0.00	0.00	0.00	0.00	0.00	0.30
0.00	0.00	0.00	0.00	0.00	0.00

SSR(i) =

0.00	3.08	3.77	4.20	4.51	4.75

LSR(i) =

0.00	2.18	2.67	2.97	3.19	3.36

Any Difference underscored by an aster is significant (P > .05)
Any Difference not underscored is not significant (P= or < .05)

6. SCHEFFE TEST

A COMPARISON IN THE SCHEFFE TEST IS REFERRED TO AS A CONTRAST. SUPPOSE WE WISH TO COMPARE FOUR DRUG MEANS X(1),X(2),X(3) AND X(4). PERHAPS DRUG 1 IS A PLACEBO AND WE WOULD LIKE TO COMPARE IT TO DRUGS 2,3 AND 4. THE HULL HYPOTHESIS WOULD BE DRUGS 2,3 AND 4 ARE NO DIFFERENT FROM DRUG 1. A CONTRAST C THAT WOULD REPRESENT THIS COMPARISON WOULD BE:

$$C = u(1) - 1/3\ u(2) - 1/3 u(3) - 1/3\ u(4)$$

SO A CONTRAST IS A LINEAR FUNCTION OF THE POPULATION MEANS THAT SATISFIES THE REQUIREMENT THAT THE SUM OF THE COEFFICIENTS IS ZERO.

$$C = \sum c(I)\ u(I) \text{ AND } \sum c(I) = 0$$

OTHER COMPARISONS THAT COULD BE MADE ARE:

(1) DRUGS 2 AND 3: $C = 0\ u(1) + u(2) - u(3) + 0\ u(4)$

(2) DRUGS 1 AND 2 VS DRUGS 3 AND 4:

$$C = 1/2\ u(1) + 1/2\ u(2) - 1/2\ u(3) - 1/2\ u(4)$$

THE SCHEFFE TEST ESTABLISHES CONFIDENCE INTERVALS FOR A CONTRAST C THAT TAKE THE FORM:

$$C \pm S \sqrt{MSE \left(\ c(I)^2 / N(I)\right)}$$

WHERE:

$C = \sum c(I)\ X(I)$

$S^2 = (K - 1)*F$, F HAS (K-1) AND MSE DEGREES OF FREEDOM

MSE = MEAN SQUARE ERROR FORM THE ANALYSIS OF VARIANCE TABLE

N(I) = NUMBER OF OBSERVATIONS FOR TREATMENT GROUP I

A COMPARISON OF DRUG 1 TO DRUGS 2,3, AND 4 THAT LEAD TO A CONFIDENCE INTERVAL THAT DID NOT INCLUDE ZERO COULD BE INTERPRETED AS: "THE AVERAGE RESPONSE OF DRUGS 2,3 AND 4 IS DIFFERENT FROM THAT OF DRUG 1".

EXAMPLE:

TREATMENTS	MEANS
A	4.0
B	5.0
C	6.7
D	7.0
E	4.7
F	7.3

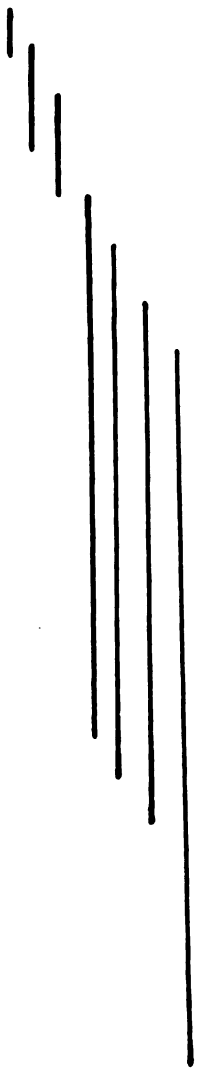
ONE WAY ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	F.
TREATMENTS	5	29.11	5.82	3.88
ERROR	12	18.00	1.50	
TOTAL	17	47.11		

$$SCHEEFE = \sqrt{3.88} * \sqrt{1.5 * 4} = 4.82$$

PLANNED COMPARISONS	DECISION
$\{\bar{X}A, \bar{X}B\} = \{\bar{X}C, \bar{X}D, \bar{X}E, \bar{X}F\}$	
4.0 5.0 = 6.7 7.0 4.7 7.3 = 7.7	(*)

TABLE 1. AVERAGE PERCENTAGE BUNT IN 9 REGIONAL TESTS OF SEED TREATMENT FUNGICIDES FOR THE CONTROL OF BUNT IN WINTER WHEAT 1/

TREATMENT	PERCENTAGE BUNT	STATISTICAL SIGNIFICANCE
CHECK - UNTREATED	55.3	
PANOGEN 15	34.4	
PANOGEN 15	26.3	
CAPTON - HCB 50-20	20.9	
TERRACLOR	11.1	
DOW HCB	10.3	
CAPTON - HCB 50-20	9.6	
NO BUNT	8.3	
SANOCIDE	7./	
TERRACLOR	6.5	
ANTICARIE	5.6	
CAPTON - HCB 50-20	5.5	
NO BUNT	4.6	
DOW HCB	4.6	
PANOGEN 15	3.8	
ANTICARIE	3.3	
DOW HCB	2.9	
TERRACLOR	2.9	
SANOCIDE	2.4	
SANOCIDE	2.1	
ANTICARIE	2.0	
NO BUNT	2.0	

1/ TABLE 2 OF ARTICLE BY LAURENCE H. PURDY, PUBLISHED IN U.S.D.A., PLANT DISEASE REPORTER 39:844-849. 1955

TABLE 2. AVERAGE HEIGHT OF FALL GROWTH OF LOTS OF RANGER ALFALFA PRODUCED AT DIFFERENT LOCATIONS 1/

AVERAGE HEIGHT OF PLANTS (INCHES) GROWN FROM SEED PRODUCED AT SPECIFIED LOCATIONS.							
	MONT.	WASH.	MONT.	CALIF.	ARIZ.	MEX.	ARIZ
HEIGHT, INCHES	3.4	3.5	3.6	3.8	4.1	4.9	5.3
STATISTICAL SIGNIFICANCE							

1/ MODIFIED FROM TABLE 1 OF ARTICLE BY DALE SMITH, AGRON. JOUR. 47: 201-205. 1955

TABLE 3. EFFECT OF LOCATION ON THE OIL CONTENT OF CORN GRAIN. 1/

LOCATION	MEAN (%)	STAT. SIG. 2/
WILLIAMSBURG	4.4	A
PETERSBURG	4.3	B
CHARLOTTE COURTHOUSE	4.2	C D
STAUNTON	4.2	C D
ONLEY	4.1	D
CHATHAM	4.0	E
BLACKSBURG	3.9	E

1/ PART OF TABLE 1 OF ARTICLE BY C.F. GENTER, J.F. EHEART, AND W.N. LINKOUS, PUBLISHED IN AGRON. JOUR. 48:63-70. 1956

2/ STAT. SIG. MEANS STATISTICAL SIGNIFICANCE. MEAN FOLLOWED BY LETTER "A" IS SIGNIFICANTLY DIFFERENT FROM THOSE MEANS NOT HAVING "A"; THOSE FOLLOWED BY "B" ARE SIGNIFICANTLY DIFFERENT FROM THOSE NOT HAVING "B", ETC.

TABLE 4. YIELDS (IN LBS.) OF TOBACCO AS INFLUENCED BY TIME OF PLOWING UNDER DIFFERENT COVER CROPS.1/

KIND OF COVER CROP	TIME OF PLOWING				COVER CROP AVERAGE	
	EARLY		LATE			
	YIELD	STAT. SIG.2/	YIELD	STAT. SIG.2/	YIELD	STAT. SIG.2/
NONE	940		932		936	
RYEGRASS	1013		955		984	
RYEGRASS-VE	1226		1396		1311	
VETCH	1219		1427		1323	
RYE-VETCH	1290		1500		1395	
WHEAT-VETCH	1343		1457		1400	

1/ DATA REPORTED BY C.S.BRITT AND C.S. SLATER AT THE 1956 MEETING OF THE AMERICAN SOCIETY OF AGRONOMY.

2/ STAT. SIG. MEANS STATISTICAL SIGNIFICANCE.

ECONOMIC ANALYSIS

THE ECONOMIC ANALYSIS PROVIDES THE BIOLOGICAL SCIENTISTS METHODOLOGIES TO ANALYSE THE DATA IN NOT ONLY BIOLOGICAL TERMS, BUT ALSO IN ECONOMICAL TERMS.

FOLLOWING PAGES PROVIDE EXAMPLES TO:

A) CALCULATE THE NET BENEFIT, AND
B) MARGINAL RETURNS FOR EACH TREATMENT;
C) SENSITIVITY ANALYSIS;
D) SOME RISK MEASURES.

TO EXPLAIN THE ECONOMIC ANALYSIS, WE WILL USE THE SAMPLE DATA PRESENTED IN TABLE 1. THESE ARE RESULTS OF FERTILIZER TRIALS IN MAIZE PRODUCTION. THE TRIALS TESTED FOUR LEVELS OF NITROGEN IN FIVE REPLICATES.

THE PURPOSE OF THESE TRIALS WAS TO DERIVE RECOMMENDED NITROGEN LEVELS FOR FARMERS OF THE DOMAIN (SINGLE EXPERIMENT).

THE YIELD CURVE IN FIGURE 1 PROVIDES A GRAPHIC PICTURE OF THE RESULTING AVERAGE YIELD RESPONSE.

A) NET BENEFIT: TABLES 1 UP TO 5 WE PRESENT INTERMEDIATE STEPS TO EVALUATE NET BENEFIT.

- TABLE 1 SHOW THE AVERAGE YIELD FOR EACH, FOLLOWED BY NET YIELD (ADJUSTED YIELD) AFTER ADJUSTING DOWN-WARD 20% FOR ASSUMED HARVEST AND STORAGE LOSSES.

- THE MARKET PRICE FOR SHELLED MAIZE IN THIS AREA IS $4.00/KG. BUT AFTER MAKING CORRECTIONS DUE TO HARVEST COST = $1.00 WHICH INCLUDES SHELLING, TRANSPORTATION COSTS AND SHRINKAGE, WE DETERMINE THAT THE FIELD PRICE OF MAIZE AS $3.00 (SEE TABLE 2.)

- FREQUENTLY, MAIZE IS NOT THE ONLY PRODUCT WITH ECONOMIC VALUE THAT COMES FORM MAIZE FIELDS. LEAVES, TASSELS AND STRAW MAY ALL HAVE VALUE TO THE FARMER. GROSS FIELD BENEFITS FOR BY-PRODUCTS SHOULD BE ADDED TO GROSS FIELD BENEFITS FOR GRAIN IN ORDER TO OBTAIN TOTAL GROSS FIELD BENEFITS. (SEE TABLE 3.)

- THE CALCULATION OF TOTAL COSTS THAT VARY IS AT TIMES COMPLICATED BY TRANSPORT CHARGES FOR BULKY PURCHASE INPUTS, E.G. FERTILIZER AND SEEDS. THIS CAN HAVE A LARGE IMPACT ON TREATMENT COSTS WHERE TRANSPORT COSTS ARE HIGH. FOR EXAMPLE, CONSIDER THE FOLLOWING CALCULATION OF THE FIELD PRICE OF NITROGEN.

\$3.80/KG	PRICE OF ARE IN STORE
.80/KG	TRANSPORT TO FIELD
\$4.60/KG	PRICE OF AREA IN THE FIELD
\$4.60 / 0.46 = \$10.00	PRICE OF N IN THE FIELD, IN THE FORM OF AREA (46%N)

TO FIND THE COST OF NITROGEN FOR A GIVEN N DOSE, ONE ONLY HAS TO MULTIPLY THIS FIELD PRICE BY THE DOSE (E.G. 10 X 50 = \$5.00/HA). (SEE TABLE 4.)

- NET BENEFITS ARE DEFINED AS:

"TOTAL GROSS FIELD BENEFIT MINUS TOTAL VARIABLE COSTS"

GROSS FIELD BENEFITS WERE DISCUSSED IN TABLE 2. TOTAL VARIABLE COSTS ARE DEFINES AS: THE SUM OF FIELD COSTS FOR ALL INPUTS WHICH ARE AFFECTED BY HE CHOICE (ALTERNATIVE). VARIABLE COSTS CAN CONSIST OF EITHER MONEY COSTS OR OPPORTUNITY COSTS OR BOTH. NET BENEFIT SHOULD NOT BE CONFUSED WITH "PROFITS". RECALL THAT ONLY COSTS THAT VARY OVER TREATMENTS NEED BE INCLUDED

IN THE NET BENEFIT CALCULATION I.E. COSTS WHICH DO NOT VARY NEED NOT BE TAKEN INTO ACCOUNT. IT SHOULD BE NOTED, HOWEVER, THAT THE INCLUSION OF COSTS THAT DO NOT VARY OVER TREATMENTS WILL NOT MAKE THE ECONOMICAL ANALYSIS INCORRECT. INFACT THE RATE OF RETURN TO INVESTMENT CAPITAL WILL NOT CHANGE AT ALL IF NO VARYING COSTS ARE INCLUDED. (SEE TABLE 5.)

- THE NET BENEFIT CURVE. THIS CURVE SHOWS THE RELATIONSHIP BETWEEN THE VARIABLE COSTS OF THE ALTERNATIVES AND THE AVERAGE NET BENEFITS FORM THE ALTERNATIVES. IN FIGURE 2, WE HAVE PLOTTED EACH OF THE FERTILIZER TREATMENTS FROM TABLE 5 ACCORDING TO THE NET BENEFIT FROM THE TREATMENT AND THE VARIABLE COSTS OF THE TREATMENT. THE SOLID LINE IS THE NET BENEFIT CURVE.

TWO ASPECTS OF THIS NET BENEFIT CURVE ARE NOTEWORTHY. THE FIRST IS THAT THE CURVE RISES STEEPLY AT FIRST, THEN RISES MORE SLOWLY TO PEAK, THE CURVE SHOWS DIMINISHING RETURNS TO NITROGEN EXPENDITURE, THIS IS IMPORTANT BECAUSE IT DEMONSTRATES CLEARLY THAT WE CAN REDUCE COSTS CONSIDERABLY FROM THE POINT OF MAXIMUM NET BENEFIT WITH LITTLE REDUCTION IN THOSE BENEFITS.

THE SECOND INTERESTING ASPECT OF THE NET BENEFIT CURVE IS ITS SHAPE BETWEEN 0 AND 100 N LEVELS. THE TWO SOLID LINE SEGMENTS DROP BELOW THE BROKEN LINE. WE NORMALLY EXPECT THESE CURVES TO BEGIN STEEPLY, WITH THE SLOPE GRADUALLY FALLING AS EXPENDITURE ON INPUTS INCREASES. THE IRREGULARITY MAY BE DUE TO A NITROGEN INTERACTION AT LOW FERTILIZER LEVEL OR IT MAY BE DUE TO CHANCE.

THERE IS SURELY NO REASON TO CONDUCT ANY FURTHER TRIAL WITH NITROGEN COST IN EXCESS OF $4440. ON THE OTHER

HAND THERE MAY BE SOME NITROGEN LEVEL WHICH WOULD RESULT IN POINTS ABOVE THE BROKEN LINE, SO IT WOULD SEEM WISE TO EXPERIMENT FURTHER WITH TREATMENT COSTING BETWEEN $2900 - $4440.

B) MARGINAL RETURNS THE PURPOSE OF MARGINAL ANALYSIS IS TO REVEAL JUST HOW THE NET BENEFITS FROM AN INVESTMENT INCREASE AS THE AMOUNT INVESTED INCREASES.

HERE, MARGINAL ANALYSIS IS BASED ON THE MARGINAL RATE OF RETURN, WHICH IS DEFINED AS THE INCREMENT IN NET BENEFITS DIVIDED BY THE INCREMENT IN COST THAT VARY, AS ONE MOVES FROM ONE TREATMENT TO THE NEXT MOST EXPENSIVE TREATMENT.

MRR = (INCREMENT NB / INCREMENT TVC) * 100

THIS RATE CAN BE FRUITFULLY INTERPRETED AS THE PERCENT RETURN ON INVESTMENT CAPITAL, AFTER THAT CAPITAL HAS BEEN REPAID.

ECONOMIC RECOMMENDATIONS ARE MADE BASED ON THE "MINIMUM RATE OF RETURN" (COST OF CAPITAL). IF SOME MARGINAL RATE OF RETURN IS GREATER THAT THE COST OF CAPITAL, THE INVESTMENT IS ACCEPTED AS PROFITABLE. (SEE TABLE 6.)

C) SENSITIVITY ANALYSIS VARIABILITY FROM YEAR TO YEAR AND FARMER TO FARMER IN PRICES PAID AS RECEIVED IS A FACT OF LIFE WHICH YOU MUST SOMEHOW CONSIDER.

WITH PRODUCT PRICES IT IS SOMETIMES TEMPTING TO USE GUARANTEED PRICES. WE ALL KNOW, HOWEVER, THAT THE PRICES WHICH FARMERS ACTUALLY RECEIVE OFTEN DIFFER FROM GUARANTEED PRICES. ALSO YOUR ESTIMATES OF PRODUCT PRICES ARE APT TO BE IN ERROR BECAUSE OF

SEASON TO SEASON VARIABILITY. SO ACCOMPLISH ALL RECALCULATION AFTER CHANGES IN PERTINENT PARAMETERS.

D) RISK ANALYSIS TABLE 7 FIRST SHOWS THE TREATMENT NUMBERS, LABELS AND NUMBER OF OBSERVATIONS. THE MEAN NET BENEFIT PER TREATMENT IS THEN REPEATED FROM THE NET BENEFIT TABLE. THE FINAL FOUR ROWS OF THE RISK TABLE GIVE VARIOUS MEASURES OF NET BENEFIT VARIABILITY, WHICH WE WILL EXAMINE AS AN INDICATOR OF RISK TO THE FARMER FROM ADOPTION OF ONE OR ANOTHER TREATMENT. THE STANDARD DEVIATION OF THE POOLED OBSERVATIONS CAN BE USED TO CALCULATE THE PROBABILITY OF THE FARMER SECURING A NET BENEFIT OF AT LEAST SOME SPECIFIED LEVEL.

IN GENERAL WE ARE LOOKING FOR TREATMENTS WHICH OFFER HIGH NET BENEFITS BUT LOW STANDARD DEVIATIONS, EXAMINE THE INDEX OF VARIABILITY.

TABLE 1. ADJUSTING FOR POST-HARVEST LOSS.

VARIABLES	TREATMENTS			
	N-0	N-50	N-100	N-150
YIELD 1 (KG/HA)	1050	1400	2200	2350
YIELD 2 (KG/HA)	1080	1450	2300	2300
YIELD 3 (KG/HA)	1100	1500	2450	2690
YIELD 4 (KG/HA)	1170	1650	2450	3000
YIELD 5 (KG/HA)	1100	1500	2350	2585
AVERAGE YIELD (KG/HA)	1100	1500	2350	2585
ADJUSTED YIELD (KG/HA) *	880	1200	1880	2068

* YIELD ADJUSTEMENT = 20%

Fig 1. Average Yield Response to N.

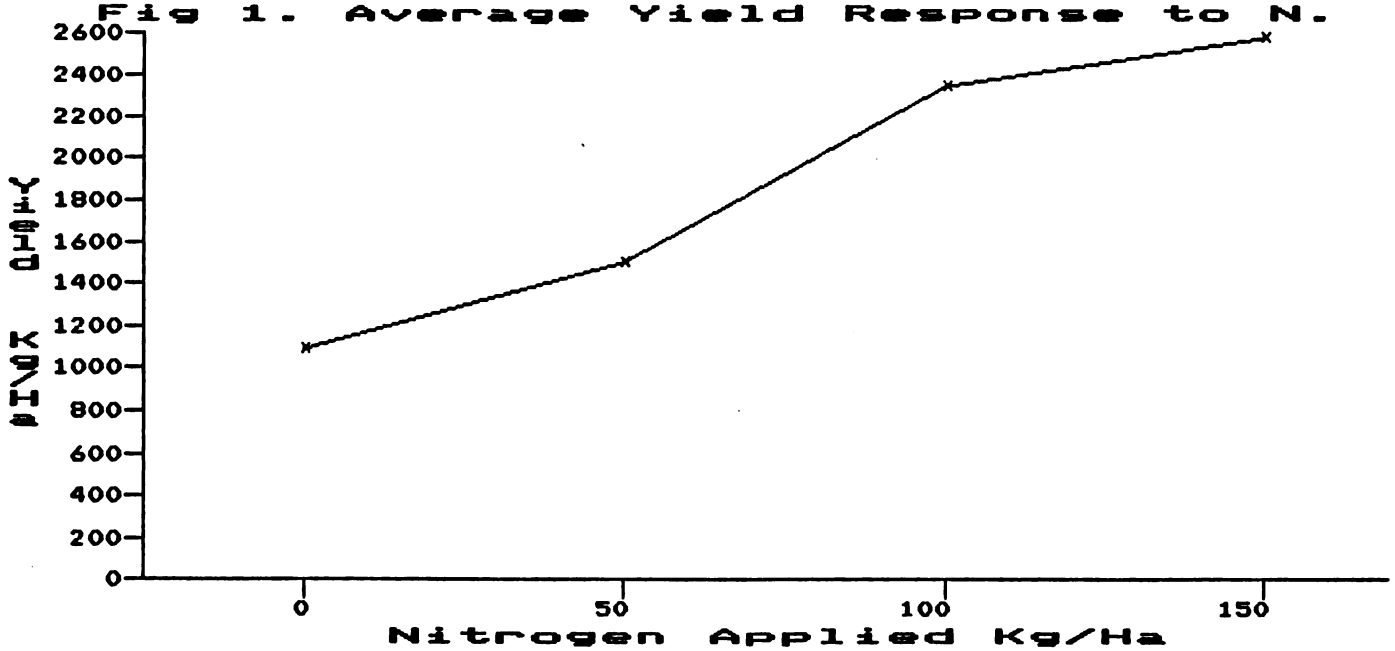


TABLE 2. GROSS FIELD BENEFITS.

VARIABLES	TREATMENTS			
	N-0	N-50	N-100	N-150
AVERAGE YIELD (KG/HA)	1100	1500	2350	2585
ADJUSTED YIELD (KG/HA)	880	1200	1880	2068
GROSS FIELD BENEFIT * ($/HA)	2640	3600	5640	6204

* MAIZE FIELD PRICE = $3.00 / KG.

TABLE 3. VALUE OF BY-PRODUCTS.

VARIABLES	TREAIMENTS			
	N-0	N-50	N-100	N-150
MAIZE YIELD (KG/HA)	1100	1500	2350	2585
STRAW YIELD (KG/HA)	950	1400	2400	2700
ADJUSTED MAIZE YIELD (KG/HA)	880	1200	1880	2068
ADJUSTED STRAW YIELD (KG/HA) *	855	1260	2160	2430
GROSS FIELD BENEFIT-STRAW ($/HA) **	256	378	648	729
TOTAL GROSS FIELD BENEFIT ($/HA)	2896	3978	6288	6933

* YIELD ADJUSTEMENT 10%
** FIELD PRICE OF STRAW = $0.30 KG.

TABLE 4. VARIABLE COSTS.

VARIABLES	TREATMENTS			
	N-0	N-50	N-100	N-150
COST OF NITROGEN ($/HA) *	0	500	1000	1500
APPLICATION COST ($/HA)	0	200	200	200

* FIELD PRICE OF N = $10.0 KG.

TABLE 5. NET BENEFIT.

VARIABLES	TREATMENTS			
	N-0	N-50	N-100	N-150
AVERAGE YIELD (KG/HA)	1100	1500	2350	2585
ADJUSTED YIELD (KG/HA)	880	1200	1880	2068
GROSS BENEFIT ($/HA)	2640	3600	5640	6204
COST OF NITROGEN ($/HA)	0	500	1000	1500
APPLICATION COST ($/HA)	0	200	200	200
TOTAL VARIABLE COSTS	0	700	1200	1700
NET BENEFITS ($/HA)	2640	2900	4440	4504

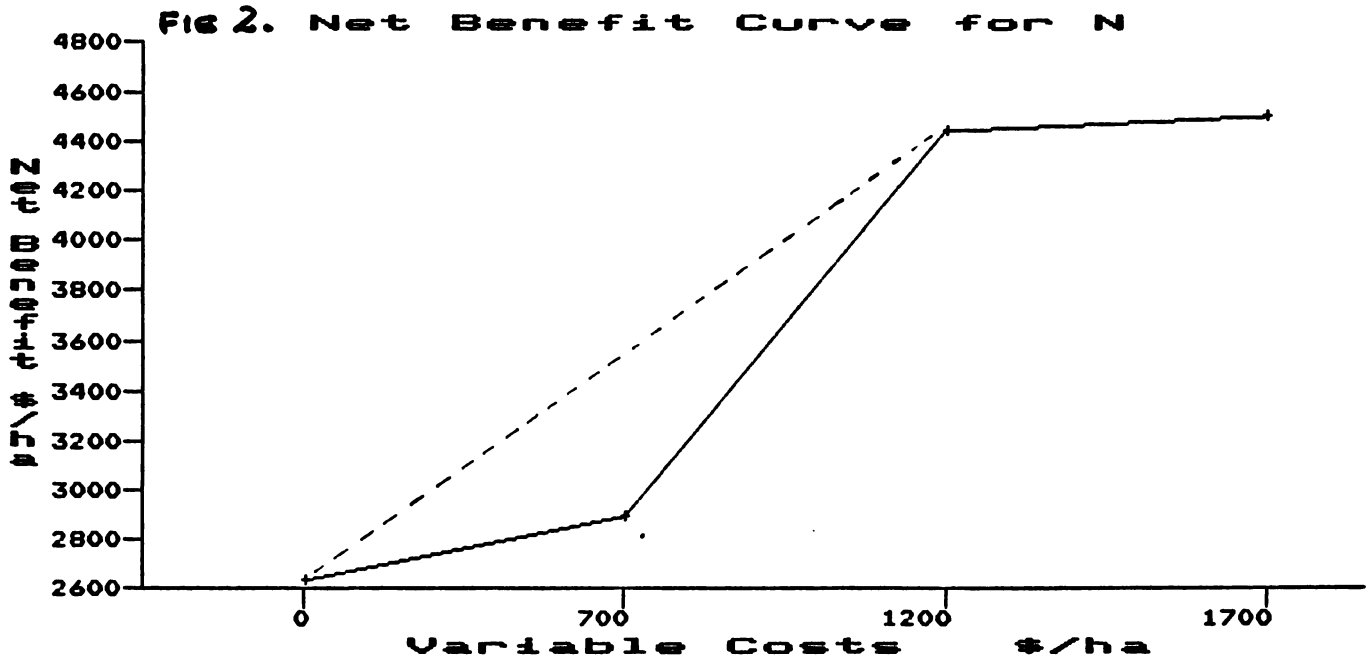


Fig 2. Net Benefit Curve for N
Net Benefit $/ha
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
0
700
1200
1700
Variable Costs $/ha

TABLE 6. MARGINAL RETURN.

VARIABLES	TREATMENTS			
	N-0	N-50	N-100	N-150
NET BENEFITS	2640	2900	4440	4504
TOTAL VARIABLE COSTS	0	700	1200	1700
MARGINAL NET BENEFIT	0	260	1540	64
MARGINAL VARIABLE COSTS	0	700	500	500
MARGINAL RATE OF RETURN	0	37	308	13

TABLE 7. RISK ANALYSIS.

VARIABLES	TREATMENTS			
	N-0	N-50	N-100	N-150
NO. OF CASES	5	5	5	5
MEAN BENEFIT	2640	2900	4440	4504
STANDARD DEVIATION	106	225	255	679
INDEX OF VARIABILITY %	4	8	6	15
MINIMUM NET BENEFIT	2520	2660	4080	3820
AVERAGE LOWEST 2 CASES	2556	2720	4200	3880

PART 2

PLANNING UNIT — MAFCA

First Short Course on Communication and Technical Writing.

Table 1. Experimental Data (Original Values).

Duncan Test

t Short Course on Communication and Technical Writing.

9.60	58.10	61.00	61.50	67.60	71.20	71.30
0.00	8.50	11.40	11.90	18.00	21.60	21.70
		*******	*******	*******	*******	*******
0.00	0.00	2.90	3.40	9.50	13.10	13.20
					*******	*******
0.00	0.00	0.00	0.50	6.60	10.20	10.30
0.00	0.00	0.00	0.00	6.10	9.70	9.80
0.00	0.00	0.00	0.00	0.00	3.60	3.70
0.00	0.00	0.00	0.00	0.00	0.00	0.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00
(i) =						
0.00	2.89	3.04	3.12	3.20	3.25	3.29
(i) =						
0.00	10.53	11.07	11.37	11.66	11.84	11.99

Difference underscored by an aster is significant (P > .05)
Difference not underscored is not significant (P= or < .05)

Table 5

Percentiles of the Studentized Range Statistic

$1 - \alpha = .95$

	r																		
ν	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	18.0	27.0	32.8	37.1	40.4	43.1	45.4	47.4	49.1	50.6	52.0	53.2	54.3	55.4	56.3	57.2	58.0	58.8	59.6
2	6.08	8.33	9.80	10.9	11.7	12.4	13.0	13.5	14.0	14.4	14.7	15.1	15.4	15.7	15.9	16.1	16.4	16.6	16.8
3	4.50	5.91	6.82	7.50	8.04	8.48	8.85	9.18	9.46	9.72	9.95	10.2	10.3	10.5	10.7	10.8	11.0	11.1	11.2
4	3.93	5.04	5.76	6.29	6.71	7.05	7.35	7.60	7.83	8.03	8.21	8.37	8.52	8.66	8.79	8.91	9.03	9.13	9.23
5	3.64	4.60	5.22	5.67	6.03	6.33	6.58	6.80	6.99	7.17	7.32	7.47	7.60	7.72	7.83	7.93	8.03	8.12	8.21
6	3.46	4.34	4.90	5.30	5.63	5.90	6.12	6.32	6.49	6.65	6.79	6.92	7.03	7.14	7.24	7.34	7.43	7.51	7.59
7	3.34	4.16	4.68	5.06	5.36	5.61	5.82	6.00	6.16	6.30	6.43	6.55	6.66	6.76	6.85	6.94	7.02	7.10	7.17
8	3.26	4.04	4.53	4.89	5.17	5.40	5.60	5.77	5.92	6.05	6.18	6.29	6.39	6.48	6.57	6.65	6.73	6.80	6.87
9	3.20	3.95	4.41	4.76	5.02	5.24	5.43	5.59	5.74	5.87	5.98	6.09	6.19	6.28	6.36	6.44	6.51	6.58	6.64
10	3.15	3.88	4.33	4.65	4.91	5.12	5.30	5.46	5.60	5.72	5.83	5.93	6.03	6.11	6.19	6.27	6.34	6.40	6.47
11	3.11	3.82	4.26	4.57	4.82	5.03	5.20	5.35	5.49	5.61	5.71	5.81	5.90	5.98	6.06	6.13	6.20	6.27	6.33
12	3.08	3.77	4.20	4.51	4.75	4.95	5.12	5.27	5.39	5.51	5.61	5.71	5.80	5.88	5.95	6.02	6.09	6.15	6.21
13	3.06	3.73	4.15	4.45	4.69	4.88	5.05	5.19	5.32	5.43	5.53	5.63	5.71	5.79	5.86	5.93	5.99	6.05	6.11
14	3.03	3.70	4.11	4.41	4.64	4.83	4.99	5.13	5.25	5.36	5.46	5.55	5.64	5.71	5.79	5.85	5.91	5.97	6.03
15	3.01	3.67	4.08	4.37	4.59	4.78	4.94	5.08	5.20	5.31	5.40	5.49	5.57	5.65	5.72	5.78	5.85	5.90	5.96
16	3.00	3.65	4.05	4.33	4.56	4.74	4.90	5.03	5.15	5.26	5.35	5.44	5.52	5.59	5.66	5.73	5.79	5.84	5.90
17	2.98	3.63	4.02	4.30	4.52	4.70	4.86	4.99	5.11	5.21	5.31	5.93	5.47	5.54	5.61	5.67	5.73	5.79	5.84
18	2.97	3.61	4.00	4.28	4.49	4.67	4.82	4.96	5.07	5.17	5.27	5.35	5.43	5.50	5.57	5.63	5.69	5.74	5.79
19	2.96	3.59	3.98	4.25	4.47	4.65	4.79	4.92	5.04	5.14	5.23	5.31	5.39	5.46	5.53	5.59	5.65	5.70	5.75
20	2.95	3.58	3.96	4.23	4.45	4.62	4.77	4.90	5.01	5.11	5.20	5.28	5.36	5.43	5.49	5.55	5.61	5.66	5.71
24	2.92	3.53	3.90	4.17	4.37	4.54	4.68	4.81	4.92	5.01	5.10	5.18	5.25	5.32	5.38	5.44	5.49	5.55	5.59
30	2.89	3.49	3.85	4.10	4.30	4.46	4.60	4.72	4.82	4.92	5.00	5.08	5.15	5.21	5.27	5.33	5.38	5.43	5.47
40	2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.73	4.82	4.90	4.98	5.04	5.11	5.16	5.22	5.27	5.31	5.36
60	2.83	3.40	3.74	3.98	4.16	4.31	4.44	4.55	4.65	4.73	4.81	4.88	4.94	5.00	5.06	5.11	5.15	5.20	5.24
120	2.80	3.36	3.68	3.92	4.10	4.24	4.36	4.47	4.56	4.64	4.71	4.78	4.84	4.90	4.95	5.00	5.04	5.09	5.13
∞	2.77	3.31	3.63	3.86	4.03	4.17	4.29	4.39	4.47	4.55	4.62	4.68	4.74	4.80	4.85	4.89	4.93	4.97	5.01

TABLE A.9B

TABLE OF t FOR TWO-SIDED COMPARISONS BETWEEN p TREATMENT MEANS AND A CONTROL FOR A JOINT CONFIDENCE COEFFICIENT OF $P = .95$ AND $P = .99$

Error df	P	p = number of treatment means, excluding control								
		1	2	3	4	5	6	7	8	9
5	.95	2.57	3.03	3.39	3.66	3.88	4.06	4.22	4.36	4.49
	.99	4.03	4.63	5.09	5.44	5.73	5.97	6.18	6.36	6.53
6	.95	2.45	2.86	3.18	3.41	3.60	3.75	3.88	4.00	4.11
	.99	3.71	4.22	4.60	4.88	5.11	5.30	5.47	5.61	5.74
7	.95	2.36	2.75	3.04	3.24	3.41	3.54	3.66	3.76	3.86
	.99	3.50	3.95	4.28	4.52	4.71	4.87	5.01	5.13	5.24
8	.95	2.31	2.67	2.94	3.13	3.28	3.40	3.51	3.60	3.68
	.99	3.36	3.77	4.06	4.27	4.44	4.58	4.70	4.81	4.90
9	.95	2.26	2.61	2.86	3.04	3.18	3.29	3.39	3.48	3.55
	.99	3.25	3.63	3.90	4.09	4.24	4.37	4.48	4.57	4.65
10	.95	2.23	2.57	2.81	2.97	3.11	3.21	3.31	3.39	3.46
	.99	3.17	3.53	3.78	3.95	4.10	4.21	4.31	4.40	4.47
11	.95	2.20	2.53	2.76	2.92	3.05	3.15	3.24	3.31	3.38
	.99	3.11	3.45	3.68	3.85	3.98	4.09	4.18	4.26	4.33
12	.95	2.18	2.50	2.72	2.88	3.00	3.10	3.18	3.25	3.32
	.99	3.05	3.39	3.61	3.76	3.89	3.99	4.08	4.15	4.22
13	.95	2.16	2.48	2.69	2.84	2.96	3.06	3.14	3.21	3.27
	.99	3.01	3.33	3.54	3.69	3.81	3.91	3.99	4.06	4.13
14	.95	2.14	2.46	2.67	2.81	2.93	3.02	3.10	3.17	3.23
	.99	2.98	3.29	3.49	3.64	3.75	3.84	3.92	3.99	4.05
15	.95	2.13	2.44	2.64	2.79	2.90	2.99	3.07	3.13	3.19
	.99	2.95	3.25	3.45	3.59	3.70	3.79	3.86	3.93	3.99
16	.95	2.12	2.42	2.63	2.77	2.88	2.96	3.04	3.10	3.16
	.99	2.92	3.22	3.41	3.55	3.65	3.74	3.82	3.88	3.93
17	.95	2.11	2.41	2.61	2.75	2.85	2.94	3.01	3.08	3.13
	.99	2.90	3.19	3.38	3.51	3.62	3.70	3.77	3.83	3.89
18	.95	2.10	2.40	2.59	2.73	2.84	2.92	2.99	3.05	3.11
	.99	2.88	3.17	3.35	3.48	3.58	3.67	3.74	3.80	3.85
19	.95	2.09	2.39	2.58	2.72	2.82	2.90	2.97	3.04	3.09
	.99	2.86	3.15	3.33	3.46	3.55	3.64	3.70	3.76	3.81
20	.95	2.09	2.38	2.57	2.70	2.81	2.89	2.96	3.02	3.07
	.99	2.85	3.13	3.31	3.43	3.53	3.61	3.67	3.73	3.78
24	.95	2.06	2.35	2.53	2.66	2.76	2.84	2.91	2.96	3.01
	.99	2.80	3.07	3.24	3.36	3.45	3.52	3.58	3.64	3.69
30	.95	2.04	2.32	2.50	2.62	2.72	2.79	2.86	2.91	2.96
	.99	2.75	3.01	3.17	3.28	3.37	3.44	3.50	3.55	3.59
40	.95	2.02	2.29	2.47	2.58	2.67	2.75	2.81	2.86	2.90
	.99	2.70	2.95	3.10	3.21	3.29	3.36	3.41	3.46	3.50
60	.95	2.00	2.27	2.43	2.55	2.63	2.70	2.76	2.81	2.85
	.99	2.66	2.90	3.04	3.14	3.22	3.28	3.33	3.38	3.42
120	.95	1.98	2.24	2.40	2.51	2.59	2.66	2.71	2.76	2.80
	.99	2.62	2.84	2.98	3.08	3.15	3.21	3.25	3.30	3.33
∞	.95	1.96	2.21	2.37	2.47	2.55	2.62	2.67	2.71	2.75
	.99	2.58	2.79	2.92	3.01	3.08	3.14	3.18	3.22	3.25

SOURCE: This table is reproduced from "A multiple comparison procedure for comparing several treatments with a control," *J. Am. Stat. Assn.*, 50: 1096–1121 (1955), with permission of the author, C. W. Dunnett, and the editor.

PART 2

PLANNING UNIT — MAFCA

First Short Course on Communication and Technical Writing.

Table 1. Experimental Data (Original Values).

Duncan Test

t Short Course on Communication and Technical Writing.

8.60	58.10	61.00	61.50	67.60	71.20	71.30
0.00	8.50	11.40	11.90	18.00	21.60	21.70
		*******	*******	*******	*******	*******
0.00	0.00	2.90	3.40	9.50	13.10	13.20
					*******	*******
0.00	0.00	0.00	0.50	6.60	10.20	10.30
0.00	0.00	0.00	0.00	6.10	9.70	9.80
0.00	0.00	0.00	0.00	0.00	3.60	3.70
0.00	0.00	0.00	0.00	0.00	0.00	0.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00
(1) =						
0.00	2.89	3.04	3.12	3.20	3.25	3.29
(1) =						
0.00	10.53	11.07	11.37	11.66	11.84	11.99

Difference underscored by an aster is significant (P > .05)
Difference not underscored is not significant (P= or < .05)

Table 5

Percentiles of the Studentized Range Statistic

$1 - \alpha = .95$

	r																		
ν	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	18.0	27.0	32.8	37.1	40.4	43.1	45.4	47.4	49.1	50.6	52.0	53.2	54.3	55.4	56.3	57.2	58.0	58.8	59.6
2	6.08	8.33	9.80	10.9	11.7	12.4	13.0	13.5	14.0	14.4	14.7	15.1	15.4	15.7	15.9	16.1	16.4	16.6	16.8
3	4.50	5.91	6.82	7.50	8.04	8.48	8.85	9.18	9.46	9.72	9.95	10.2	10.3	10.5	10.7	10.8	11.0	11.1	11.2
4	3.93	5.04	5.76	6.29	6.71	7.05	7.35	7.60	7.83	8.03	8.21	8.37	8.52	8.66	8.79	8.91	9.03	9.13	9.23
5	3.64	4.60	5.22	5.67	6.03	6.33	6.58	6.80	6.99	7.17	7.32	7.47	7.60	7.72	7.83	7.93	8.03	8.12	8.21
6	3.46	4.34	4.90	5.30	5.63	5.90	6.12	6.32	6.49	6.65	6.79	6.92	7.03	7.14	7.24	7.34	7.43	7.51	7.59
7	3.34	4.16	4.68	5.06	5.36	5.61	5.82	6.00	6.16	6.30	6.43	6.55	6.66	6.76	6.85	6.94	7.02	7.10	7.17
8	3.26	4.04	4.53	4.89	5.17	5.40	5.60	5.77	5.92	6.05	6.18	6.29	6.39	6.48	6.57	6.65	6.73	6.80	6.87
9	3.20	3.95	4.41	4.76	5.02	5.24	5.43	5.59	5.74	5.87	5.98	6.09	6.19	6.28	6.36	6.44	6.51	6.58	6.64
10	3.15	3.88	4.33	4.65	4.91	5.12	5.30	5.46	5.60	5.72	5.83	5.93	6.03	6.11	6.19	6.27	6.34	6.40	6.47
11	3.11	3.82	4.26	4.57	4.82	5.03	5.20	5.35	5.49	5.61	5.71	5.81	5.90	5.98	6.06	6.13	6.20	6.27	6.33
12	3.08	3.77	4.20	4.51	4.75	4.95	5.12	5.27	5.39	5.51	5.61	5.71	5.80	5.88	5.95	6.02	6.09	6.15	6.21
13	3.06	3.73	4.15	4.45	4.69	4.88	5.05	5.19	5.32	5.43	5.53	5.63	5.71	5.79	5.86	5.93	5.99	6.05	6.11
14	3.03	3.70	4.11	4.41	4.64	4.83	4.99	5.13	5.25	5.36	5.46	5.55	5.64	5.71	5.79	5.85	5.91	5.97	6.03
15	3.01	3.67	4.08	4.37	4.59	4.78	4.94	5.08	5.20	5.31	5.40	5.49	5.57	5.65	5.72	5.78	5.85	5.90	5.96
16	3.00	3.65	4.05	4.33	4.56	4.74	4.90	5.03	5.15	5.26	5.35	5.44	5.52	5.59	5.66	5.73	5.79	5.84	5.90
17	2.98	3.63	4.02	4.30	4.52	4.70	4.86	4.99	5.11	5.21	5.31	5.93	5.47	5.54	5.61	5.67	5.73	5.79	5.84
18	2.97	3.61	4.00	4.28	4.49	4.67	4.82	4.96	5.07	5.17	5.27	5.35	5.43	5.50	5.57	5.63	5.69	5.74	5.79
19	2.96	3.59	3.98	4.25	4.47	4.65	4.79	4.92	5.04	5.14	5.23	5.31	5.39	5.46	5.53	5.59	5.65	5.70	5.75
20	2.95	3.58	3.96	4.23	4.45	4.62	4.77	4.90	5.01	5.11	5.20	5.28	5.36	5.43	5.49	5.55	5.61	5.66	5.71
24	2.92	3.53	3.90	4.17	4.37	4.54	4.68	4.81	4.92	5.01	5.10	5.18	5.25	5.32	5.38	5.44	5.49	5.55	5.59
30	2.89	3.49	3.85	4.10	4.30	4.46	4.60	4.72	4.82	4.92	5.00	5.08	5.15	5.21	5.27	5.33	5.38	5.43	5.47
40	2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.73	4.82	4.90	4.98	5.04	5.11	5.16	5.22	5.27	5.31	5.36
60	2.83	3.40	3.74	3.98	4.16	4.31	4.44	4.55	4.65	4.73	4.81	4.88	4.94	5.00	5.06	5.11	5.15	5.20	5.24
120	2.80	3.36	3.68	3.92	4.10	4.24	4.36	4.47	4.56	4.64	4.71	4.78	4.84	4.90	4.95	5.00	5.04	5.09	5.13
∞	2.77	3.31	3.63	3.86	4.03	4.17	4.29	4.39	4.47	4.55	4.62	4.68	4.74	4.80	4.85	4.89	4.93	4.97	5.01

TABLE A.9B

TABLE OF t FOR TWO-SIDED COMPARISONS BETWEEN p TREATMENT MEANS AND A CONTROL FOR A JOINT CONFIDENCE COEFFICIENT OF $P = .95$ AND $P = .99$

Error df	P	p = number of treatment means, excluding control								
		1	2	3	4	5	6	7	8	9
5	.95	2.57	3.03	3.39	3.66	3.88	4.06	4.22	4.36	4.49
	.99	4.03	4.63	5.09	5.44	5.73	5.97	6.18	6.36	6.53
6	.95	2.45	2.86	3.18	3.41	3.60	3.75	3.88	4.00	4.11
	.99	3.71	4.22	4.60	4.88	5.11	5.30	5.47	5.61	5.74
7	.95	2.36	2.75	3.04	3.24	3.41	3.54	3.66	3.76	3.86
	.99	3.50	3.95	4.28	4.52	4.71	4.87	5.01	5.13	5.24
8	.95	2.31	2.67	2.94	3.13	3.28	3.40	3.51	3.60	3.68
	.99	3.36	3.77	4.06	4.27	4.44	4.58	4.70	4.81	4.90
9	.95	2.26	2.61	2.86	3.04	3.18	3.29	3.39	3.48	3.55
	.99	3.25	3.63	3.90	4.09	4.24	4.37	4.48	4.57	4.65
10	.95	2.23	2.57	2.81	2.97	3.11	3.21	3.31	3.39	3.46
	.99	3.17	3.53	3.78	3.95	4.10	4.21	4.31	4.40	4.47
11	.95	2.20	2.53	2.76	2.92	3.05	3.15	3.24	3.31	3.38
	.99	3.11	3.45	3.68	3.85	3.98	4.09	4.18	4.26	4.33
12	.95	2.18	2.50	2.72	2.88	3.00	3.10	3.18	3.25	3.32
	.99	3.05	3.39	3.61	3.76	3.89	3.99	4.08	4.15	4.22
13	.95	2.16	2.48	2.69	2.84	2.96	3.06	3.14	3.21	3.27
	.99	3.01	3.33	3.54	3.69	3.81	3.91	3.99	4.06	4.13
14	.95	2.14	2.46	2.67	2.81	2.93	3.02	3.10	3.17	3.23
	.99	2.98	3.29	3.49	3.64	3.75	3.84	3.92	3.99	4.05
15	.95	2.13	2.44	2.64	2.79	2.90	2.99	3.07	3.13	3.19
	.99	2.95	3.25	3.45	3.59	3.70	3.79	3.86	3.93	3.99
16	.95	2.12	2.42	2.63	2.77	2.88	2.96	3.04	3.10	3.16
	.99	2.92	3.22	3.41	3.55	3.65	3.74	3.82	3.88	3.93
17	.95	2.11	2.41	2.61	2.75	2.85	2.94	3.01	3.08	3.13
	.99	2.90	3.19	3.38	3.51	3.62	3.70	3.77	3.83	3.89
18	.95	2.10	2.40	2.59	2.73	2.84	2.92	2.99	3.05	3.11
	.99	2.88	3.17	3.35	3.48	3.58	3.67	3.74	3.80	3.85
19	.95	2.09	2.39	2.58	2.72	2.82	2.90	2.97	3.04	3.09
	.99	2.86	3.15	3.33	3.46	3.55	3.64	3.70	3.76	3.81
20	.95	2.09	2.38	2.57	2.70	2.81	2.89	2.96	3.02	3.07
	.99	2.85	3.13	3.31	3.43	3.53	3.61	3.67	3.73	3.78
24	.95	2.06	2.35	2.53	2.66	2.76	2.84	2.91	2.96	3.01
	.99	2.80	3.07	3.24	3.36	3.45	3.52	3.58	3.64	3.69
30	.95	2.04	2.32	2.50	2.62	2.72	2.79	2.86	2.91	2.96
	.99	2.75	3.01	3.17	3.28	3.37	3.44	3.50	3.55	3.59
40	.95	2.02	2.29	2.47	2.58	2.67	2.75	2.81	2.86	2.90
	.99	2.70	2.95	3.10	3.21	3.29	3.36	3.41	3.46	3.50
60	.95	2.00	2.27	2.43	2.55	2.63	2.70	2.76	2.81	2.85
	.99	2.66	2.90	3.04	3.14	3.22	3.28	3.33	3.38	3.42
120	.95	1.98	2.24	2.40	2.51	2.59	2.66	2.71	2.76	2.80
	.99	2.62	2.84	2.98	3.08	3.15	3.21	3.25	3.30	3.33
∞	.95	1.96	2.21	2.37	2.47	2.55	2.62	2.67	2.71	2.75
	.99	2.58	2.79	2.92	3.01	3.08	3.14	3.18	3.22	3.25

SOURCE: This table is reproduced from "A multiple comparison procedure for comparing several treatments with a control," *J. Am. Stat. Assn.*, 50: 1096–1121 (1955), with permission of the author, C. W. Dunnett, and the editor.

Table A.7

Significant Studentized Ranges for 5% and 1% Level New Multiple-range Test

Error *df*	Protection level	p = number of means for range being tested													
		2	3	4	5	6	7	8	9	10	12	14	16	18	20
1	.05	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
	.01	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
2	.05	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09
	.01	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
3	.05	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
	.01	8.26	8.5	8.6	8.7	8.8	8.9	8.9	9.0	9.0	9.0	9.1	9.2	9.3	9.3
4	.05	3.93	4.01	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02
	.01	6.51	6.8	6.9	7.0	7.1	7.1	7.2	7.2	7.3	7.3	7.4	7.4	7.5	7.5
5	.05	3.64	3.74	3.79	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83
	.01	5.70	5.96	6.11	6.18	6.26	6.33	6.40	6.44	6.5	6.6	6.6	6.7	6.7	6.8
6	.05	3.46	3.58	3.64	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68
	.01	5.24	5.51	5.65	5.73	5.81	5.88	5.95	6.00	6.0	6.1	6.2	6.2	6.3	6.3
7	.05	3.35	3.47	3.54	3.58	3.60	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61
	.01	4.95	5.22	5.37	5.45	5.53	5.61	5.69	5.73	5.8	5.8	5.9	5.9	6.0	6.0
8	.05	3.26	3.39	3.47	3.52	3.55	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56
	.01	4.74	5.00	5.14	5.23	5.32	5.40	5.47	5.51	5.5	5.6	5.7	5.7	5.8	5.8
9	.05	3.20	3.34	3.41	3.47	3.50	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52
	.01	4.60	4.86	4.99	5.08	5.17	5.25	5.32	5.36	5.4	5.5	5.5	5.6	5.7	5.7
10	.05	3.15	3.30	3.37	3.43	3.46	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.48
	.01	4.48	4.73	4.88	4.96	5.06	5.13	5.20	5.24	5.28	5.36	5.42	5.48	5.54	5.55
11	.05	3.11	3.27	3.35	3.39	3.43	3.44	3.45	3.46	4.46	3.46	3.46	3.46	3.47	3.48
	.01	4.39	4.63	4.77	4.86	4.94	5.01	5.06	5.12	5.15	5.24	5.28	5.34	5.38	5.39
12	.05	3.08	3.23	3.33	3.36	3.40	3.42	3.44	3.44	3.46	3.46	3.46	3.46	3.47	3.48
	.01	4.32	4.55	4.68	4.76	4.84	4.92	4.96	5.02	5.07	5.13	5.17	5.22	5.24	5.26
13	.05	3.06	3.21	3.30	3.35	3.38	3.41	3.42	3.44	3.45	3.45	3.46	3.46	3.47	3.47
	.01	4.26	4.48	4.62	4.69	4.74	4.84	4.88	4.94	4.98	5.04	5.08	5.13	5.14	5.15
14	.05	3.03	3.18	3.27	3.33	3.37	3.39	3.41	3.42	3.44	3.45	3.46	3.46	3.47	3.47
	.01	4.21	4.42	4.55	4.63	4.70	4.78	4.83	4.87	4.91	4.96	5.00	5.04	5.06	5.07
15	.05	3.01	3.16	3.25	3.31	3.36	3.38	3.40	3.42	3.43	3.44	3.45	3.46	3.47	3.47
	.01	4.17	4.37	4.50	4.58	4.64	4.72	4.77	4.81	4.84	4.90	4.94	4.97	4.99	5.00

TABLE A.7 (Continued)

SIGNIFICANT STUDENTIZED RANGES FOR 5% AND 1% LEVEL NEW MULTIPLE-RANGE TEST

Error *df*	Protection level	p = number of means for range being tested													
		2	3	4	5	6	7	8	9	10	12	14	16	18	20
16	.05	3.00	3.15	3.23	3.30	3.34	3.37	3.39	3.41	3.43	3.44	3.45	3.46	3.47	3.47
	.01	4.13	4.34	4.45	4.54	4.60	4.67	4.72	4.76	4.79	4.84	4.88	4.91	4.93	4.94
17	.05	2.98	3.13	3.22	3 28	3.33	3.36	3.38	3.40	3.42	3.44	3.45	3.46	3.47	3.47
	.01	4.10	4.30	4.41	4.50	4.56	4.63	4.68	4.72	4.75	4.80	4.83	4.86	4.88	4.89
18	.05	2.97	3.12	3.21	3.27	3.32	3.35	3.37	3.39	3.41	3.43	3.45	3.46	3.47	3.47
	.01	4.07	4.27	4.38	4.46	4.53	4.59	4.64	4.68	4.71	4.76	4.79	4.82	4.84	4.85
19	.05	2.96	3.11	3.19	3.26	3.31	3.35	3.37	3.39	3.41	3.43	3.44	3.46	3.47	3.47
	.01	4.05	4.24	4.35	4.43	4.50	4.56	4.61	4.64	4.67	4.72	4.76	4.79	4.81	4.82
20	.05	2.95	3.10	3.18	3.25	3.30	3.34	3.36	3.38	3.40	3.43	3.44	3.46	3.46	3.47
	.01	4.02	4.22	4.33	4.40	4.47	4.53	4.58	4.61	4.65	4.69	4.73	4.76	4.78	4.79
22	.05	2.93	3.08	3.17	3.24	3.29	3.32	3.35	3.37	3.39	3.42	3.44	3.45	3.46	3.47
	.01	3.99	4.17	4.28	4.36	4.42	4.48	4.53	4.57	4.60	4.65	4.68	4.71	4.74	4.75
24	.05	2.92	3.07	3.15	3.22	3.28	3.31	3.34	3.37	3.38	3.41	3.44	3.45	3.46	3.47
	.01	3.96	4.14	4.24	4.33	4.39	4.44	4.49	4.53	4.57	4.62	4.64	4.67	4.70	4.72
26	.05	2.91	3.06	3.14	3.21	3.27	3.30	3.34	3.36	3.38	3.41	3.43	3.45	3.46	3.47
	.01	3.93	4.11	4.21	4.30	4.36	4.41	4.46	4.50	4.53	4.58	4.62	4.65	4.67	4.69
28	.05	2.90	3.04	3.13	3.20	3.26	3.30	3.33	3.35	3.37	3.40	3.43	3.45	3.46	3.47
	.01	3.91	4.08	4.18	4.28	4.34	4.39	4.43	4.47	4.51	4.56	4.60	4.62	4.65	4.67
30	.05	2.89	3.04	3.12	3.20	3.25	3.29	3.32	3.35	3.37	3.40	3.43	3.44	3.46	3.47
	.01	3.89	4.06	4.16	4.22	4.32	4.36	4.41	4.45	4.48	4.54	4.58	4.61	4.63	4.65
40	.05	2.86	3.01	3.10	3.17	3.22	3.27	3.30	3.33	3.35	3.39	3.42	3.44	3.46	3.47
	.01	3.82	3.99	4.10	4.17	4.24	4.30	4.34	4.37	4.41	4.46	4.51	4.54	4.57	4.59
60	.05	2.83	2.98	3.08	3.14	3.20	3.24	3.28	3.31	3.33	3.37	3.40	3.43	3.45	3.47
	.01	3.76	3.92	4.03	4.12	4.17	4.23	4.27	4.31	4.34	4.39	4.44	4.47	4.50	4.53
100	.05	2.80	2.95	3.05	3.12	3.18	3.22	3.26	3.29	3.32	3.36	3.40	3.42	3.45	3.47
	.01	3.71	3.86	3.98	4.06	4.11	4.17	4.21	4.25	4.29	4.35	4.38	4.42	4.45	4.48
∞	.05	2.77	2.92	3.02	3.09	3.15	3.19	3.23	3.26	3.29	3.34	3.38	3.41	3.44	3.47
	.01	3.64	3.80	3.90	3.98	4.04	4.09	4.14	4.17	4.20	4.26	4.31	4.34	4.38	4.41

SOURCE: Abridged from D. B. Duncan, "Multiple range and multiple *F* tests," *Biometrics*, 11: 1–42 (1955), with the permission of the editor and the author.

TABLE A.3

VALUES OF t

df	Probability of a larger value of t, sign ignored								
	0.5	0.4	0.3	0.2	0.1	0.05	0.02	0.01	0.001
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	.765	.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	.741	.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	.727	.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
6	.718	.906	1.134	1.440	1.943	2.447	3.143	3.707	5.959
7	.711	.896	1.119	1.415	1.895	2.365	2.998	3.499	5.405
8	.706	.889	1.108	1.397	1.860	2.306	2.896	3.355	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	.685	.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	.679	.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	.677	.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
∞	.674	.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291

df	0.25	0.2	0.15	0.1	0.05	0.025	0.01	0.005	0.0005
	Probability of a larger value of t, sign considered								

SOURCE: This table is abridged from Table III of Fisher and Yates, *Statistical Tables for Biological, Agricultural, and Medical Research*, published by Oliver and Boyd Ltd., Edinburgh, 1949, by permission of the authors and publishers.

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Autor

Título First short course on
Communication and technical writing

Fecha Devolución	Nombre del solicitante